Canada

Report of the

TASK FORCE - OPERATION OIL

(Clean-up of the Arrow oil spill in Chedabucto Bay)

to

The Minister of Transport

VOLUME II

ISSUED BY THE MINISTRY OF TRANSPORT

Report of the

TASK FORCE - OPERATION OIL

(Clean-up of the Arrow oil spill in Chedabucto Bay)

to

The Minister of Transport

Cat. No.: T22-2470/2

REPORT OF THE SCIENTIFIC COORDINATION TEAM

TO THE HEAD OF THE TASK FORCE

OPERATION OIL

(THE *ARROW* INCIDENT)

JULY 1970

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"We are apt to imagine that we could discover these effects by the mere operation of our reason without experience."

- David Hume, 1748

"An Enquiry Concerning Human Understanding"

FOREWORD

On February 4, 1970, the tanker ARROW carrying some 108,000 barrels of Bunker C fuel oil grounded on Cerberus Rock in Chedabucto Bay, Nova Scotia. Over the next eight days the progressive break-up of the ship resulted in the spillage of more than half the cargo, and Canada was faced with its worst oil spill disaster in recent history. From the first, representatives of the Department of Transport and Imperial Oil Ltd., owners of the cargo, were on the scene. Scientific assistance was volunteered immediately on on ad hoc basis by several agencies and by individuals. On February 20 the Minister of Transport appointed a Task Force headed by Dr. P.D. McTaggart-Cowan with wide powers to bring to bear the full measure of coordinated resources needed to contend with the disaster. Among these were the resources of the scientific community, and to this end a scientific coordination team reporting to the Head of the Task Force was established with the broad support of the relevant federal, provincial and university research authorities. The composition and function of the team are discussed in the body of the report, Section 1.2, p. 2).

The report is a summary of the results of projects arranged by the team on behalf of the Task Force. It also presents recommendations for continuing research and development, contributing not only to improved operational systems for dealing with such incidents, but also to that greater knowledge of the interaction of spilled oil and the environment, so essential to an on-scene commander faced with daily tactical decisions and to the sound development of preventive legislation and regulations.

K. Yuen, with assistance from the members of the Scientific Coordination Team, compiled this report from a large number of project reports, memoranda and personal communications collected from among the many persons involved in Operation Oil.

On behalf of the Scientific Coordination Team and the Task Force, it is a pleasure to acknowledge with gratitude the willing, indeed enthusiastic, support given by all those with whom we have been associated in this operation.

Wm. L. Ford,
Scientific Coordinator
for Task Force, Operation Oil

July 1970

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SOME USEFUL CONVERSIONS

Throughout the course of Operation Oil, personnel from many disciplines have been involved. As a result, not only has there been usage of British and metric units but terms from the shipping and oil industries as well. Since readers familiar with one system of measurement may not find other units physically meaningful, it has not been practical in this report to adhere to one single system of measurement. Therefore some useful conversions are given below.

1 nautical mile	= 6080 feet
	= 1.15 statute miles
1 knot	= 1 nautical mile/hour
	= 1.69 feet/second
	= 0.515 metre/second
1 barrel	= 35 Imperial gallons at 60°F
	= 42 U.S. gallons at 60°F
1 drum	= 45 Imperial gallons
1 long ton	= 2240 pounds
	= 6.67 barrels
	= 232.4 Imperial gallons

15.5° API/60°F = 0.963 S.G. 60°F/60°F

275 SSF/122F = 545 centipoise at 122F

Mileages referred to in this report are nautical miles unless otherwise stated.

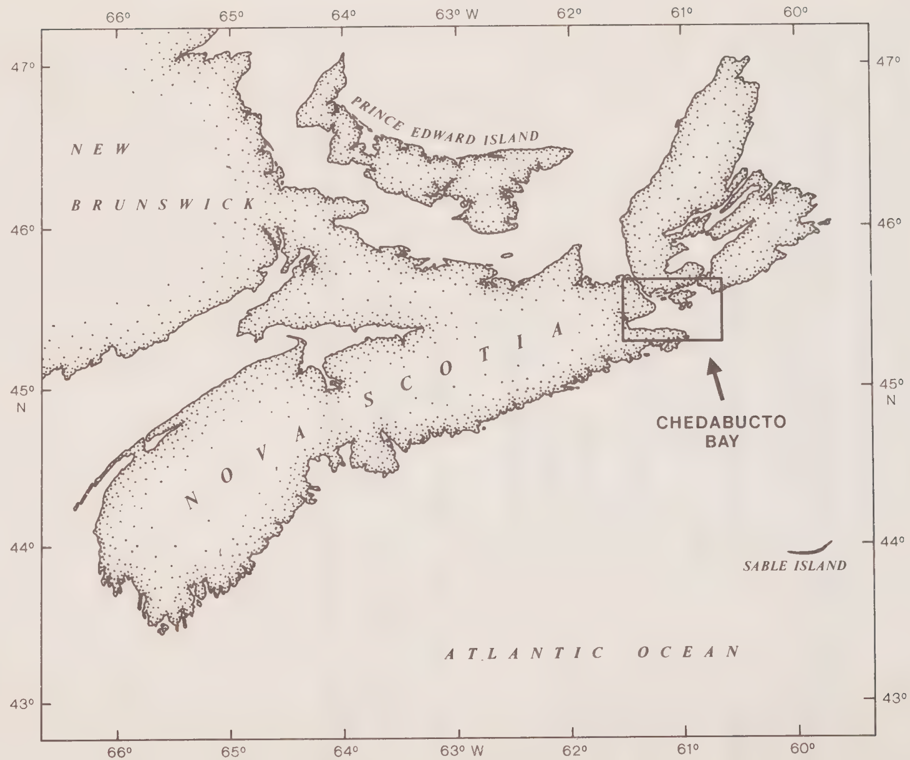


Fig. 1.1 Geographical location of Chedabucto Bay, Nova Scotia. A detailed chart of the area is shown in Figure 2.1 (centrefold).

1. INTRODUCTION

1.1 Background

On Wednesday, February 4, 1970, amidst heavy rain and winds from the southeast reportedly gusting up to 60 knots, the Liberian tanker ARROW ran aground on Cerberus Rock in Chedabucto Bay, Nova Scotia (Fig.1.1 and Fig. 2.1, centrefold). She was under charter to Imperial Oil Limited and had been en route to Nova Scotia Pulp Limited with a cargo of 108,000 barrels of Bunker C fuel oil.

In retrospect, it is apparent that the eight days immediately following the grounding were critical in determining the magnitude of the disaster. The forward half of the ARROW suffered extensive damage on grounding, and oil began to flow from the ruptured tanks. Over the next 14 hours much of this oil was transported to the shores north of Cerberus Rock by the prevailing winds and currents. As the storm moderated and the wind shifted, oil slicks, some miles in extent, were driven toward the south coast of the Bay. Some of the oil may have escaped from the Bay. On February 8, the ARROW broke in half at her No. 5 tank, the contents of which were thus spilled into the sea. Two days later the wind shifted from the northwest to the southeast and this oil in turn was driven toward the north shores of Chedabucto Bay. On February 12 the stern section sank in 90 feet of water carrying with it a good third of the cargo. The tanks containing this oil remained essentially intact, and very little oil was to escape from the stern section after it had settled to the sea bed. Gale force winds from the east and later from the southwest moved more oil into the Inhabitants Bay, Janvrin Island and Isle Madame areas. In the days following, oil moved toward the open sea.

By the eighth day, February 12, an estimated one half of the ship's cargo of oil had been released and the calamity had reached catastrophic proportions. Out of 375 statute miles of shoreline in the Bay area, 190 miles had been contaminated in varying degrees. Oil continued to issue from the forward section of the wreck, and there remained the threat of a further massive flow of oil should the after section break up before its contents could be recovered. Oil afloat in the Bay and at sea threatened fishing operations, fish-packing plants, the as-yet unpolluted shores, bird life and the marine eco-system. This was still the general nature of the situation which faced the Task Force when it began operations on February 21. Moreover, it was mid-winter. Air temperatures were generally in the range of -10 to 0°C. Gale force winds, snow, freezing rain, and rain could frequently be expected. Sea water temperatures were close to the freezing point and sea ice was building up in the sheltered bays and passages. The behaviour of the heavy Bunker C oil in this frigid environment was recognized from the beginning as a key problem in the operation and a central object of the scientific investigations. The absence of reported knowledge about any similar event in the past made the investigation a unique challenge.

1.2 The Task Force

On February 20, 1970, the Federal Minister of Transport appointed a three-man Task Force with all the necessary authority to call upon resources of men and materials required to resolve the pollution problem in Chedabucto Bay. The appointments were:-

Dr. P.D. McTaggart-Cowan, Executive Director, Science Council of Canada (as Head of the Task Force);

Dr. H. Sheffer, Vice Chairman, Defence Research Board;

Captain M.A. Martin, Maritime Command, Canadian Armed Forces.

The central objectives of the Task Force were:-

(a) To minimize the damage to the economy and ecology of the region affected by the spill or threatened by further spillage;

(b) To take full advantage of the incident to gain knowledge and understanding of, and experience with, oil spills in order to contend better with any such disasters in the future, and

(c) To recommend to the Government the necessary measures to minimize the occurrence of oil spills and, in the event of a spill, to provide an immediate response for control and clean-up.

1.3 Scientific Coordination Team

Considerable scientific participation in the incident had developed on an impromptu and rather unstructured basis during the period February 4 to 21. The Task Force, appreciative of the scientific involvement already in being, considered that in order to meet its objectives the assistance of the scientific community would be required on a substantially larger and more organized scale. On February 24 Dr. Wm. L. Ford, Director, Atlantic Oceanographic Laboratory, was seconded to "Operation Oil" as Scientific Coordinator reporting to the Task Force. His first action was to assemble a team of scientists of varied experience to work full time on the coordination of the complex of scientific and technical problems facing "Operation Oil". With the willing cooperation of colleagues in the scientific community, the Team was soon at work in quarters at the Bedford Institute, Dartmouth, Nova Scotia.

The organization and membership of the Team was:-

Scientific Corrdinator:	Dr. W.L. Ford, Atlantic Oceanographic Laboratory, Marine Sciences Branch, Department of Energy, Mines & Resources
Executive Assistant:	Mr. K.B. Yuen, Headquarters, Marine Sciences Branch, Department of Energy, Mines & Resources
Chemical Science:	Dr. A.Y. McLean, Nova Scotia Technical College
Environmental Sciences: (Physical)	Dr. C.S. Mason, Atlantic Oceanographic Laboratory, Marine Sciences Branch, Department of Energy, Mines & Resources
Environmental Sciences: (Ecological)	Dr. R.W. Trites, Marine Ecology Laboratory, Fisheries Research Board of Canada
Clean-Up Technology:	Dr. W.D. Jamieson, Atlantic Regional Laboratory, National Research Council

In addition, the post of Scientific Liaison Officer was established at Port Hawkesbury to maintain communications between the Task Force and the Scientific Coordination Team. The following shared this post at various times: Dr. F. Payne and Mr. R.W. Brown of the Defence Research Establishment Atlantic, Defence Research Board, and Mr. T.R. Foote of the Atlantic Oceanographic Laboratory.

An *ad hoc* advisory committee of senior officers of participating organizations was convened to review progress with the Scientific Coordination Team and to ensure

that measures for cooperation and coordination were commensurate with the task ahead. The members of the committee were:

Dr. J.E. Blanchard,
President, Nova Scotia Research Foundation.

Mr. R.N. Gordon,
Regional Director, Department of Fisheries & Forestry.

Dr. D.R. Idler,
Atlantic Regional Director, Research, Fisheries Research Board of Canada.

Dr. B.D. Loncarevic
Acting Director, Atlantic Oceanographic Laboratory.

Dr. A.C. Neish,
Director, Atlantic Regional Laboratory.

Dr. J.G. Retallack,
Director-General, Defence Research Establishment Atlantic.

Dr. G.A. Riley,
Director, Institute of Oceanography, Dalhousie University.

Mr. E.L. Rowe,
Director, Nova Scotia Water Resources Commission.

Mr. G.H. Watson,
Wildlife Biologist, Canadian Wildlife Service.

The Scientific Coordination Team was a management team with a contracting role to initiate and coordinate projects being carried out by various cooperating agencies. Research organizations at the Federal and Provincial level cooperated to the fullest extent and for the most part provided funds for the projects from within their own resources. Valuable volunteer and consultant assistance was received on an extensive scale from numerous university scientists and from many firms. The list of collaborators given in Chapter 10 is an indication of the breadth of scientific and technical support afforded the Team's operations.

The activities of the Scientific Coordination Team fell naturally into two categories, tactical and strategic. In the tactical category were those activities whose purpose was to provide immediate scientific and technical support to the Task Force operations. Activities of the strategic kind were those aimed primarily at taking full advantage of the situation created by the ARROW incident to contribute to scientific understanding of and to the technical ability to contend with oil pollution in general, although they could also have direct application to Task Force operations. These functions are parallel to and derive from the overall objectives of of the Task Force stated in the preceding section. The recent increase in public and governmental concern over the quality of the environment gave a sense of urgency to the task which, it is felt, has led to much more being accomplished in a shorter space of time than would have been possible a few years ago.

1.4 Scope of the Report

The report is a summary of the many scientific and technical activities arranged or monitored by the Scientific Coordination Team on behalf of the Task Force. It identifies areas of research and development which on the basis of our experience in Operation Oil are seen as being of particular importance to the advancement of the technology for contending with major oil spills and to the scientific assessment of the threat of widespread oil pollution on the high seas. It comments upon the organization of continuing research and development in this field in Canada. It is intended to serve not only as a technical supplement to the overall report of the Task Force but as a document for independent distribution to those interested in the

science and technology of oil spills and oil pollution. Accordingly, in the interest of clarity, it overlaps certain of the operational aspects of the Task Force report.

While efforts have been made to be as complete and up-to-date as possible, there are areas in which this has not been achieved. A cut-off date of May 15, 1970, was establihsed for the collection of data, technical reports and memoranda used in the compilation of this report. This is an advanced draft report which was required from Scientific Coordination for the preparation of the overall Task Force report to be submitted to the Minister of Transport by September 1, 1970. In some cases there has not been sufficient time to complete the analysis and interpretation of the field data. There are also a number of long term projects which will continue well past the September 1, 1970, reporting date. It should be noted that much of the information reported here will be reported in fuller and more complete detail by the agencies involved through the normal channels of information dissemination, such as in technical reports and in the open literature.

2. PHYSICAL ENVIRONMENTAL CONDITIONS

2.1 General Description

In this report the name Chedabucto Bay (see Fig. 2.1, centre fold) is applied to "the whole area of water entered from eastward between Michaud Point, on the south coast of Cape Breton Island, and Cranberry Island, Nova Scotia, and terminating westward in Guysborough Harbour and the Strait of Canso; the entrance however, is considered to lie between Grime Rock and Green Island" (Canadian Hydrographic Service, 1968).

At the entrance of the Bay, the water depth reaches 70 fathoms and gradually decreases towards Guysborough Harbour. The Strait of Canso, with depths up to 25 fathoms, forms a norrow extension in the northwesterly direction, terminated by the Canso Causeway. While the south shore of the Bay is very straight and the offshore regions fairly deep, the north side is characterized by a group of islands, of which the largest are Petit-de-Grat Island, Isle Madame and Janvrin Island. This group of islands is separated from Cape Breton by Lennox Passage, which stretches from the Inhabitants Bay area to St. Peters Bay. South of Isle Madame, a group of shoals stretches for about seven miles, with depths ranging from 6 to 15 fathoms. Cerberus Rock is an outcrop of one of these shoals, located at longitude 67° 06′ 24′′ W, latitude 45° 27′ 57′′ N.

After the stern section sank on February 12, the locations of the two sections of the wreck were:-

Forward section 61° 06′ 18′′ W, 45° 27′ 57′′ N

Stern section 61° 06′ 26′′ W, 45° 28′ 15′′ N

The Canadian Hydrographic Service compiled a chart of Chedabucto Bay contoured at ten-foot intervals and a detailed chart of the Cerberus Rock area. In addition, a physical scale model of the Bay (on a 4 x 8 foot base) has been constructed and will initially become part of a public display at the Noir Forge in Arichat.

2.2 Air Temperature

The ARROW incident not only took place in a cold winter environment, but during the course of Operation Oil, the climate rapidly changed to the relative warmth of early summer. These climatic features have had a tremendous influence upon both the Task Force clean-up operations and the supporting scientific and technological activities.

While processing and interpretation of recent meteorological data is still underway, the meteorological history of the Canso recording station provides some information on the typical conditions prevailing in Chedabucto Bay. Climatic "normals" of temperature, averaged over the 30-year period 1931-1960 (Meteorological Office, 1967) are given in Table 2.1 below.

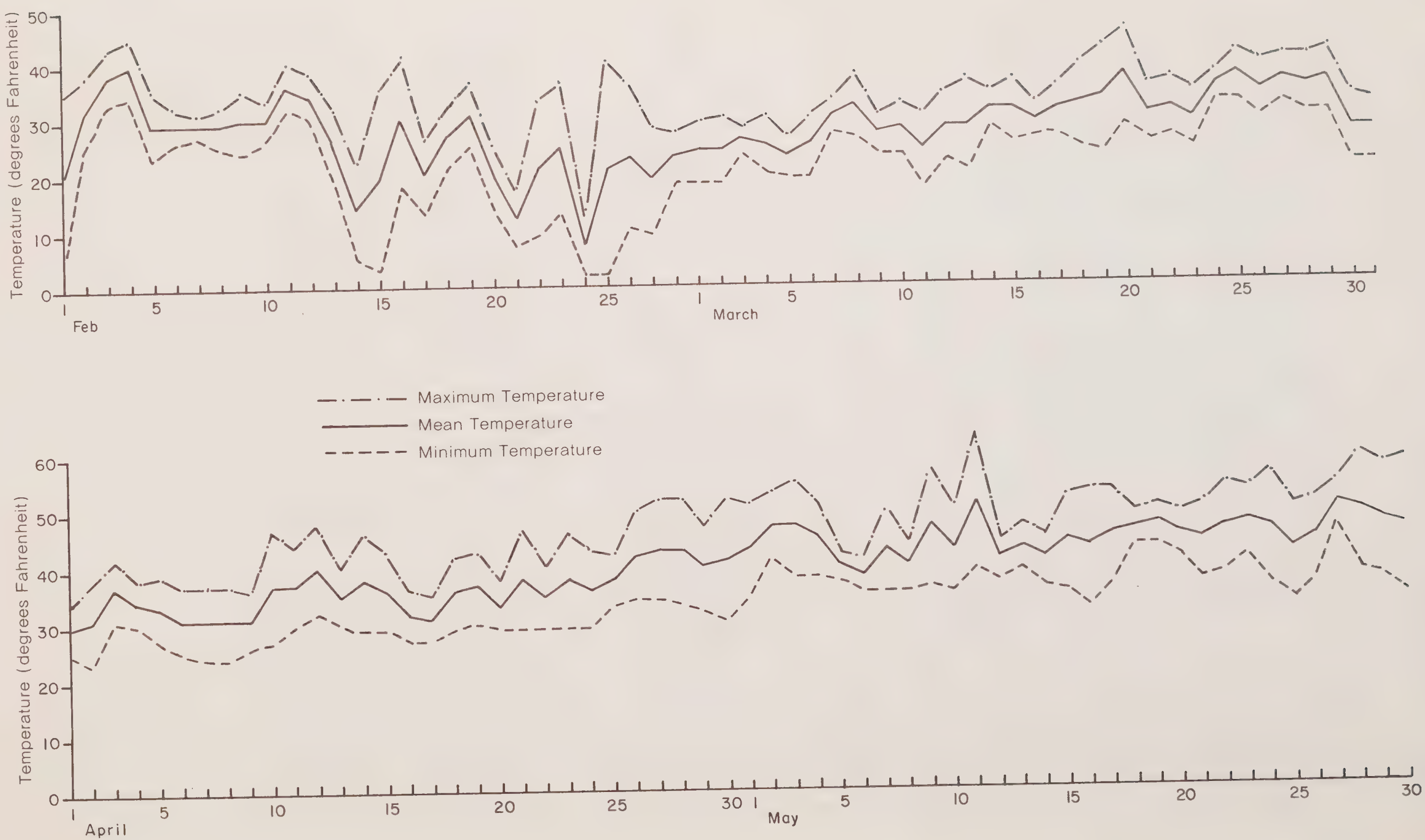


Fig. 2.2 Air temperature at Canso, N.S. Daily values of maximum, mean, and minimum temperatures are plotted for the period February 1, 1970, to May 31, 1970.

TABLE 2.1

CLIMATIC NORMALS FOR CANSO, N.S. (1931-1960)

	Jan.	Feb.	Mar.	Apr.	May	June
Maximum Daily Temperature (°F)	30.6	31.0	34.8	43.6	53.5	59.6
Mean Daily Temperature (°F)	24.5	24.7	29.3	37.0	46.2	52.0
Minimum Daily Temperature (°F)	18.2	18.3	23.8	30.3	38.8	44.4
Mean Rainfall (inches)	4.04	2.68	2.60	3.72	3.98	3.40
Mean Snowfall (inches)	9.6	15.7	15.0	4.8	0.2	0.0

It is seen that maximum, mean and minimum temperatures are all lowest in January but the corresponding values for February are only a fraction of a degree warmer. From January onward, the mean temperatures rise steadily towards their summer extremes, but the period of heavy snowfall does not occur until February and March, with an abrupt decrease in the mean snowfall in April.

In the early stages of Operation Oil, these seasonal extremes of temperature and snowfall have markedly influenced the already complex operations of debunkering and shoreline clean-up.

Recent temperature data from the Canso, N.S., recording station are shown in Figure 2.2. The maximum, mean and minimum air temperatures are shown for the period February to May, 1970, inclusive. Despite the fluctuations caused by the passage of weather systems, the variation of temperature is seen to correspond quite closely to the monthly normals given in Table 2.1. The daily minimum temperatures in early Febraury after the ARROW grounding were generally in the 20-30°F range, and not until the 13th and 14th of February did they drop to extremes in the 0-10°F range. It was at this point that large areas of shore-fast ice were formed, most notably in the Inhabitants Bay and Lennox Passage area, with the low temperatures persisting until the end of February. From March onward, the temperature continued to increase steadily, so that throughout the debunkering phase from March 13 to April 11, despite several snowstorms, the minimum daily temperatures were generally in the 20-30°F range.

2.3 Wind Data

At the time of the ARROW grounding, the only source of relevant wind data was the automatic station record at Canso. An alternative source of wind information is the surface pressure charts over the ocean, from which the winds over Chedabuto Bay can be estimated through the use of the geostrophic approximation. An analysis of 6-hourly and daily mean winds (Neu, 1970) showed that the Canso wind is generally about one-half of the gradient wind over the ocean. Southerly winds over the open ocean become more westerly near shore. Comparison of geostrophic and observed Canso winds had been carried out by Neu (1970). Mean Canso winds were lower than geostrophic winds, but both agreed in direction.

Dexter (1959) has investigated the surface winds and geostrophic winds at Sambro Lightship off Halifax and found the following relationship for the reduced geostrophic wind W (in knots)

$$W \quad 10 + 0.43\, W$$

Where W is the geostrophic wind. The mean winds quoted in this report are reduced geostrophic winds calculated from the above formula.

The mean winds at Canso during the early stages of Operation Oil are shown in Figure 2.3. It is seen that winds on February 4th were about 30 knots from the SSE

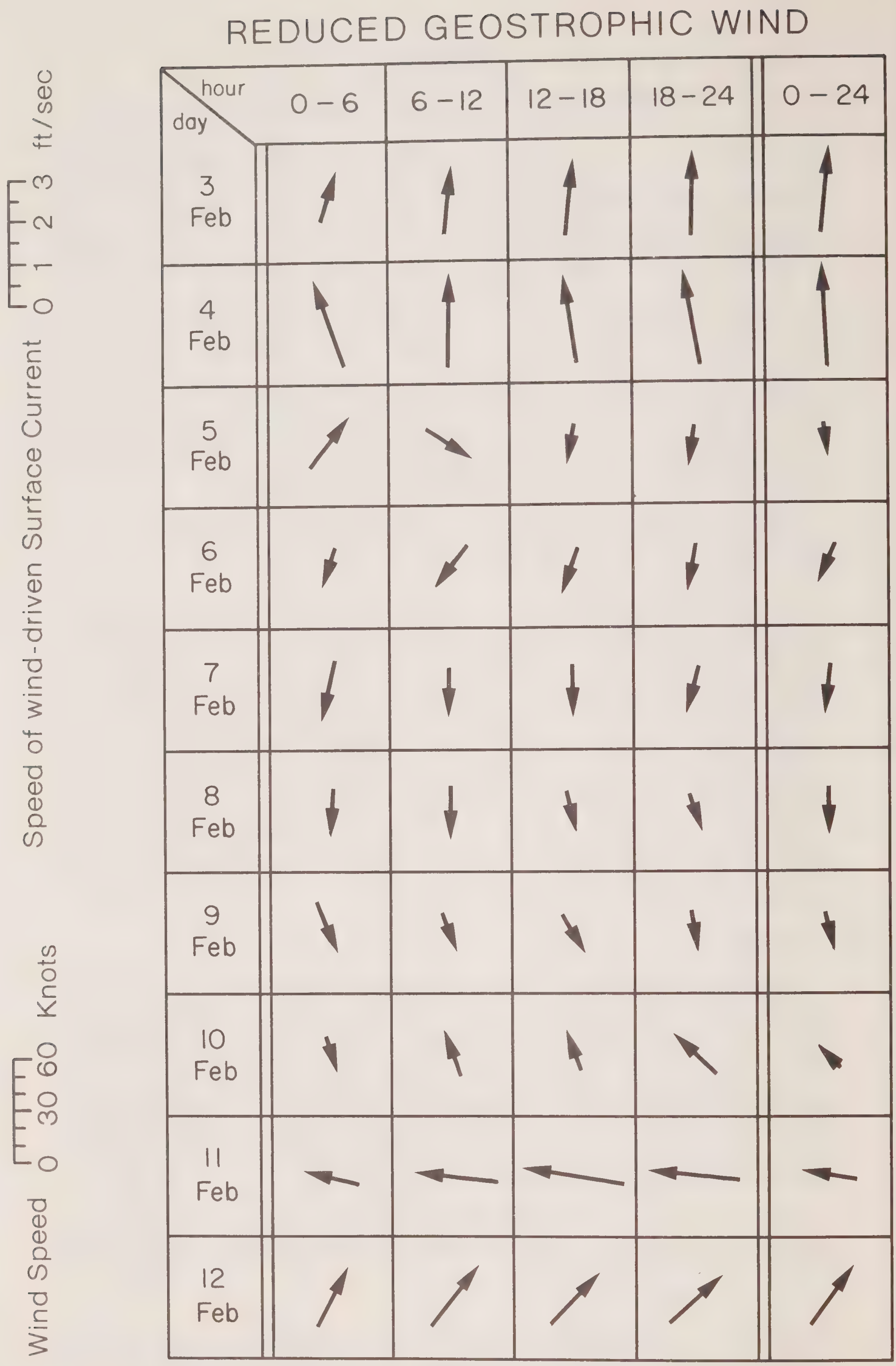


Fig. 2.3 Mean wind vectors over Chedabucto Bay, February 3-12, 1970. Six-hourly mean vectors and daily mean vectors of the reduced geostrophic wind are shown.

(gusts up to 60 knots were reported). Over the next few days, the wind slowly subsided and changed direction, first to NW and then to NE. Later a new distrubance developed, with 30-knot mean winds from the east on the 11th and the SW on the 12th. For the rest of the month, mean winds were generally weak and came from the west.

It was decided in early March that additional wind observations were needed, since winds, waves, currents and storm surges would affect debunkering and clean-up operations. Winds were also needed for the prediction of oil slick movement. Thus on March 5, in conjunction with meteorologists working for the Task Force, automatic recording stations were installed at Cap Ronde and Eddy Point. Hand anemometers were used at Cranberry Island, Jerseyman Island, Green Island and Whitehead Island. The data have been processed by the Meteorological Branch in Toronto and work is continuing on their interpretation.

2.4 Tides and Tidal Currents

The tide in Chedabucto Bay is of the semi-diurnal type, with some mixed characteristics. This type has approximately two high-waters and two low-waters daily, with a diurnal inequality. The range of the tide is nearly uniform throughout the Bay, with the range varying from 4.0 to 4.5 feet during mean tides and from 6.1 to 6.9 feet during the spring tides. The diurnal inequality can be as much as 1.0 foot.

The Reference Port for Chedabucto Bay is Port Hawkesbury. Predicitions for Port Hawkesbury are based upon the analyses of data obtained between 1952 and 1968. Since 1968, tidal measurements at that location have been discontinued. Thus during the grounding of the ARROW, no direct tidal observations were available. It should be noted that tidal predictions refer to the astronomical tide only, and do not take into account the effect of meteorological disturbances.

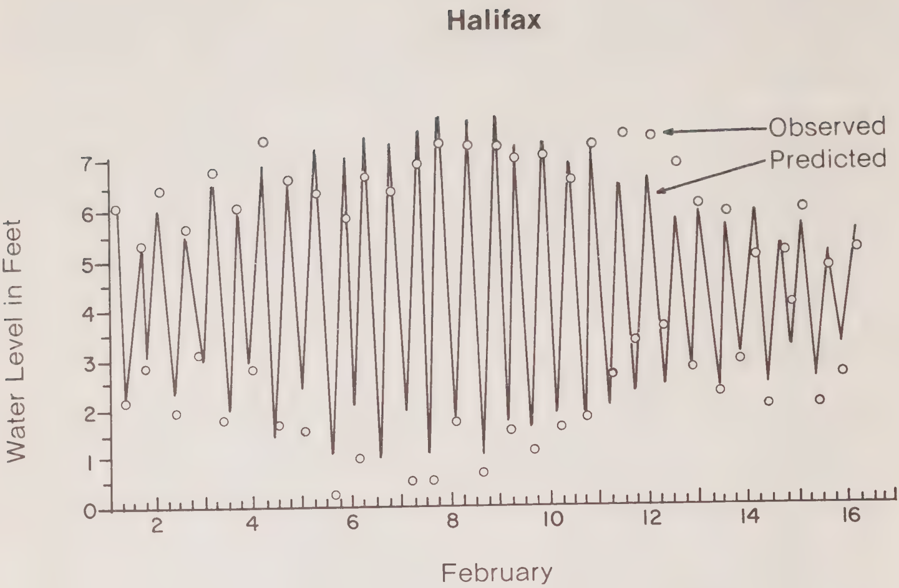
On March 13, three temporary tide gauges were installed by the Water Survey of Canada at Canso, Guysborough and Port Hawkesbury. From this later data, an analysis was made (Neu, 1970) of the relationship between the predicted and observed levels in Chedabucto Bay, and similarly for Halifax (see Fig. 2.4 p.10). It was then possible to estimate the water levels in the Bay at the time of grounding.

The ARROW grounded at 0934 Atlantic Standard Time on falling tide. On this day, water levels were 0.3 feet higher than predicted. The tidal stage was progressing towards spring tidal conditions, and by February 8 predicted low water had dropped by about one foot. A change in wind direction caused an additional 1.0 to 1.2 foot drop. This period of exceedingly low water undoubtedly contributed to the break-up of the ARROW. On February 11 and 12, in the wake of another storm, the mean water level rose more than 1.5 feet above predicted high water.

The topography in the vicinity of Cerberus Rock is extremely irregular, giving rise to the very complex current structures. For a period of 17 days in June 1968, the currents were monitored at a point 4,000 feet south of Cerberus Rock in a water depth of 160 feet, From an analysis of this data, and assuming that the wind was 30 knots from the SSE when the ARROW went aground, it has been *estimated* (Neu, 1970) that the currents near Cerberus Rock were between the limits of 0.2 ft/sec flowing southeasterly and 0.6 ft/sec northeasterly. In the estimation of the forces on the ship, however, the effect of wind upon the ship's superstructure is also an important factor.

2.5 Waves

The general size and orientation of Chedabucto Bay with respect to the direction of prevailing winds is such that waves of height greater than 7 feet or of period longer than 8 seconds are not generated locally. However, waves generated in the North Atlantic may propagate into the Bay. Waves from the south and southwest having period 10 seconds or more may be diffracted by Canso Ledge. Some energy



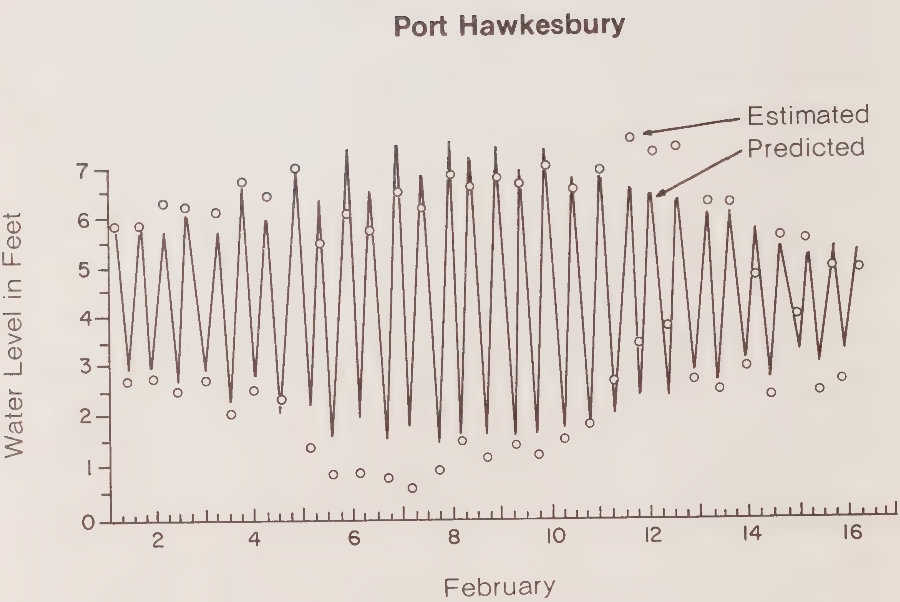


Fig. 2.4 Water levels in Chedabucto Bay, February 1-16, 1970. Top graph shows the predicted and observed water levels at Halifax, N.S. Bottom graph shows predicted and estimated water levels for Port Hawkesbury, N.S.

from the higher frequencies may also be diffracted. Within the Bay, the large shoal area extending southeast from Cerberus Rock has an average depth of perhaps 60 feet, while on all sides of the shoal the depths exceed 160 feet. Thus Cerberus Rock is likely to be a focal point for waves in the 8 to 12 second range approaching from the east and southeast sector.

The state of the sea over the ocean and continental shelf is recorded twice daily and published in the form of wave climate charts by the Canadian Armed Forces. From these charts and the synoptic weather charts of the Department of Transport, a hindcast of wave conditions outside Chedabucto Bay was made using the method of Brettschneider (Neu, 1970). On the 4th, 11th and 12th of February, estimated significant wave heights outside the Bay were in the order of 18 to 22 feet, maximum heights were 23 to 27 feet on the open sea. Refraction studies and later surveys indicated waves had about one-third these values at Cerberus Rock.

The variation of water depth results in the refraction of water waves, with convergence for decreasing depths and divergence for increasing depths. Refraction diagrams have been calculated by Neu (1970) for plane wave fronts at various angles and with various periods. A typical wave diagram is shown in Figure 2.5, for a 10-second wave at an angle of 34 degrees to the azimuth. This diagram confirms that for waves approaching approximately from an easterly direction, there is a concentation of wave energy near Cerberus Rock.

2.6 Physical Oceanographic Conditions

Throughout the period from early February to early May, a number of shipborne surveys were carried out in Chedabucto Bay and a substantial amount of oceanogrphic and hydrodynamic data collected. In addition, a pollution study initiated in 1968 is still continuing in the Strait of Canso (Lawrence, personal communication, 1970). The results summarized below, of a survey in Chedabucto Bay during the period of February 28 to March 2, 1970 (Forrester, 1970), serve as a general indication of the physical oceanographic conditions prevailing during the early stages of the Task Force operation at the height of the winter season.

At the entrance to the Bay, in late February, the mixed layer extended to depths of 120-200 feet. Towards Guysborough Harbour and in the Strait of Canso, Lennox Passage, St. Peters Bay, and the Bay of Rocks, the mixed layer extended to the bottom. Temperature and salinity in this mixed layer ranged respectively from about -1.5°C and 30.33‰ (parts per thousand) at the mouth and increased to about -0,4°C and 30.85‰ near Guysborough, +0.2°C and 30.90‰ at the Canso Causeway, and -0.8°C and 30.90‰ in St. Peters Bay. These data indicate that the water mass was well mixed throughout most of the area at the end of February. It also provides evidence of a circulation of colder, less saline water coming from the north (much of it probably originating in the Gulf of St. Lawrence) which enters Chedabucto Bay near Petit-de-Grat Island, then gradually swings over to the south shore and finally rounds Cape Canso to continue its southwestward journey. In the spring, when river run-off increased and solar radiation and ambient temperatures rose, the water in the Bay became less mixed and stratification developed.

With the observation of dispersed oil in the water column, it was desirable to estimate the flushing rates for Chedabucto Bay. A current survey was carried out to obtain a better overall picture of the circulation in the open part of the Bay, inside the entrance from Green Island to Grime Rock. During the period April 6 to 23, a number of self-recording current meters were installed (Neu, 1970) along two survey lines, one from Crichton Island to Black Point, and the other from Heath Head to George Island. In addition, shipborne metering was carried out at stations near the shore at the ends of the two survey lines. Salinity and temperature observations were also made at each of the stations on seven different occasions. It is expected that a better understanding of the circulation in the open part of Ched-

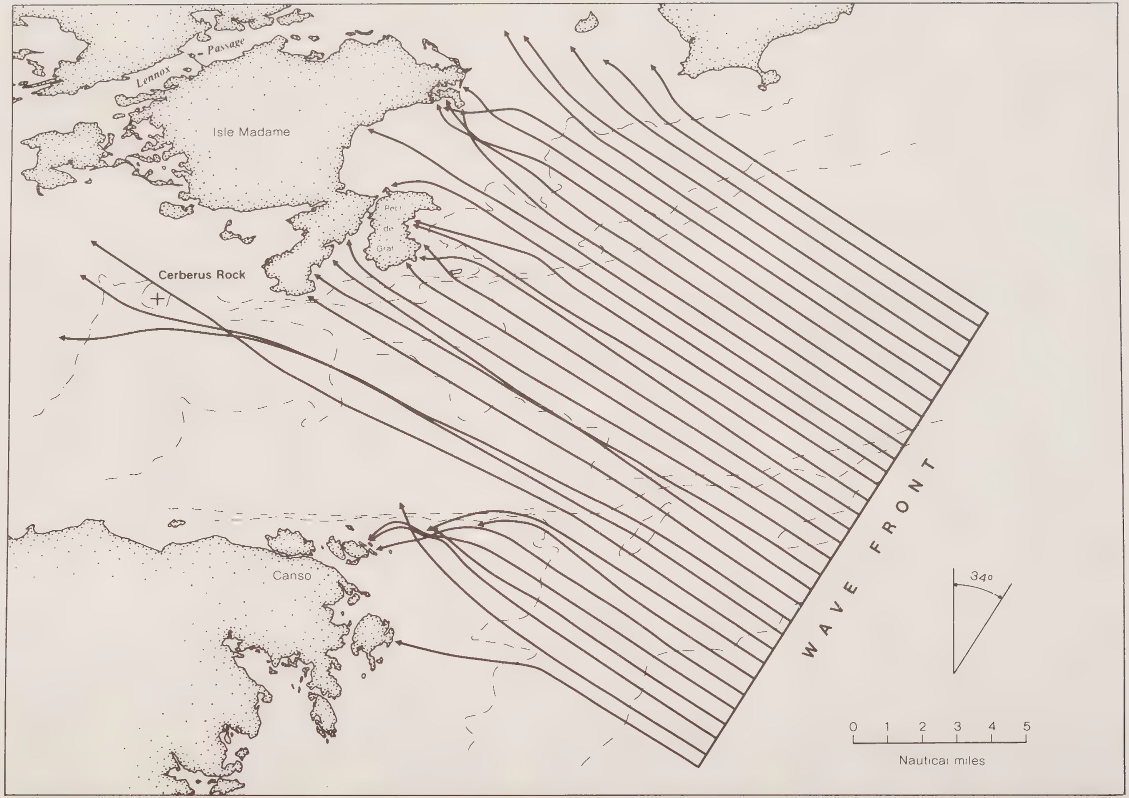


Fig. 2.5 Wave refraction diagram, Chedabucto Bay, for a wave of 10-second period with wave front at 34° azimuth.

abucto Bay proper will emerge when the processing and interpretation of the data are completed.

2.7 Geology and Coastal Morphology

The north side of Chedabucto Bay is bordered by undulating to gently rolling lowlands less than 200 feet high, developed upon relatively weak and folded carboniferous conglomerates, sandstones, shales and limestone. In contrast the south side is bounded by a steep escarpment of up to 600 feet, belonging to the Atlantic Uplands which are underlain by resistant igneous and metamorphic rocks of pre-carboniferous age.

The Bay itself represents an eroded and partially submerged fault block, clearly marked by the long straight southern shore and its submarine continuation. The irregularity of the northern shore reflects the partial drowning of the differentially eroded carboniferous rocks. Their fold axis lies along the northeastward direction in which the sea has invaded.

During the glacial period (60,000 to 13,500 years ago), material form the underlying rocks was deposited over the surrounding land and in the Bay as unsorted till and assorted deposits in the form of kames, eskers and outwash plains. On the western and northestern sides of the Bay, the bedrock is thinly covered by clay loam till, whereas parts of Isle Madame and Petit-de-Grat are thinly mantled with a gravelly, sandy till. On the floor of the Bay, a glacial till is partly buried by recent marine sediments. After the ice retreat (13,500 years ago), the sea level rose and the glacial till was redistributed into the present day sediment pattern.

The coastal landscape of Chedabucto Bay is composed of a variety of erosional and depositional land forms. The nature and extent of these forms depend upon the coastal geology and coastline processes such as waves, tides and currents. The northern coastline is a very irregularly steep-sided erosional coast. The narrow shore zone seldom exceeds 60 feet and is backed by till and bedrock cliffs. The shore forms and sediments here are apparently determined by active erosion of the till headlands and cliffs, due to ocean swell and wind waves resulting from southerly and easterly winds.

Bedrock exposures and boulder fields make up to 10-30% of the coastline in areas where most or all of the till has been removed from the shore zone and in areas of strong surf action. The remaining coastline has an intermittent cover of shingle, cobbles, gravel and coarse sand in the form of pocket beaches, small spits, bars, tombolos, and small lagoons. The high degree of compartmentalization of this indented coastline limits the amount of sediment transport, and therefore also the extent and size of the depositional features. The till is composed mainly of clay and silt size material, but the fine material has been transported either offshore or into protected bays and coves.

The western shore towards Guysborough Harbour is backed by till cliffs along most of its length and has a wider shore zone and shallower offshore zone than the north coast. Shore forms are mainly depositional, consisting of long, wide shingle, gravel and coarse sand beaches, spits, bars, cusps and tombolos, some of which enclose large lagoons.

The southern coastline is composed mainly of rocky cliffs and narrow rock and boulder shores, with only a few small beaches and bars. At the southeastern end of the Bay, beyond Canso and southwest of that, the coastline is indented with many rocky headlands, pocket sand and gravel beaches, small spits and bars, and lagoons partly enclosed by spits and bars.

3. DISTRIBUTION AND BEHAVIOUR OF RELEASED OIL

3.1 General Distribution of Oil

Following the grounding and subsequent break-up of the ARROW, nearly two-thirds of its cargo was released into the icy winter waters of Chedabucto Bay. Even five months later, we have not been able to account accurately for all of the oil released from the ARROW. However, we have been able to study where some of the oil has gone, and have gained partial insight into the mechanisms which have distributed the oil, and those which have caused changes in its properties. Perhaps one lesson to be learned here, as in many other aspects of oil pollution, is that there are still very large gaps in our knowledge and that a considerable effort is required, not only to provide new knowledge for combatting oil pollution but also in studying the basic mechanisms governing the behaviour of oil in the sea and its interactions with the environment.

Oil spilled out on the sea will, at least initially, float on the sea surface. Its movement is then largely determined by tides, waves, winds, seiches and other factors that affect surface currents. Tides are periodic and therefore predictable. Tidal currents are much more complex in nature, but can be calculated with modern hydrodynamical methods. The prediction of seiches by such methods is more difficult, since accurate prediction of certain meteorological parameters is required.

The generation of wind-driven currents has been widely studied. An empirical relationship has been widely observed, in which the wind-driven surface layer moves with the wind but at a fraction of the wind speed, 2.5 to 5% depending upon local conditions. The speed of the oil slick is assumed to be the same as that of the surface current. Observations in Chedabucto Bay (Neu, 1970) indicate surface currents to be moving at about 2.5% of the reduced geostrophic wind.

Wind-driven surface currents have played a major role in the distribution of oil about the Bay. On the 4th of February winds were 30 knots from the SSE, and oil was transported onto the shores of Isle Madame and Janvrin Island. Over the next several days the wind shifted to NW and then to north, causing contamination of the south shore in the vicinity of Canso. During this period it was observed that some oil was also carried out to sea, no doubt under the influence of favourable tides and water circulation patterns. A storm on the 11th and 12th created winds of 20 to 30 knots from the SW, which directed oil movement into the Inhabitants Bay and Janvrin Island areas. During the latter half of February winds were lighter and blew seaward, but the better weather came too late to reduce the amount of shoreline pollution since oil had by then either drifted out to sea or adhered to the shoreline.

Processing of the information from daily oil reconnaissance flights over Chedabucto Bay has not yet been completed. It is hoped that an accurate quantitative history of oil pollution throughout the Bay may be reconstructed. As a general indication of the extent of oil contamination in Chedabucto Bay, we have plotted (Fig. 3.1, p.16) all areas of shoreline that were reported to be oiled at one time or another in February (Barber, personal communication, 1970). Since not all contamination was necessarily reported during reconnaissance flights, Figure 3.1 represents the minimum of oiling that had occurred at that time. From this and later data, it is estimated that out of a total 375 statute miles of shoreline, roughly 190 miles had been oiled by early June.

The pollution of Chedabucto Bay has not been as simple as the mere driving of oil onto the shoreline. During the period February 4 to 12, calculated significant wave heights outside the Bay were seldom less than 4 feet and often reached 20 feet. At Cerberus Rock they would have been about one-third this height. As a result of

Fig 3.1 Geographical extent of shoreline contamination in Chedabucto Bay, February 1970, based on information from oil reconnaissance flights.

this wave and surf activity, the natural dispersion of some of the releasd oil has taken place. With the help of vertical mixing, this has led to a distribution of particulate oil in the water column (see Section 3.2, p. 17). An even more important result of the continual supply of mixing energy has been the conversion of the Bunker C into a sea water-in-Bunker C emulsion. This creation of water-in-oil emulsions (see Section 4.2, p. 31) has been characteristic of oil spills in general, and has led to many difficulties in predicting the behaviour of oiled shorelines and in their clean-up.

The winter environment led to further complications. The effects of cold temperatures upon the properties and behaviour of the Bunker C emulsion, indeed even of crude oil emulsions, had hitherto not been well studied. Of particular importance was the occurrence of ice and the interaction of oil with ice (see Section 3.3 p. 18) which opened up a whole new field of study. With the pollution of the shoreline and its subsequent erosion, oiled sediments (Section 3.5, p. 27) were also in movement about the Bay. Their deposition on the sea bottom also had to be considered, particularly from the point of view of assessing the effects upon the marine ecology.

3.2 Particulate Oil in the Water Column

Surveys of the distribution of oil in particulate form were carried out by the Atlantic Oceanographic Laboratory and the Marine Ecology Laboratory. These studies involved cruises by CSS DAWSON from February 11 to February 20, February 24 to March 7, and March 8 to March 15; CNAV FORT FRANCES March 25 to March 28; and CNAV SACKVILLE April 27 to May 8.

On the first cruise of the DAWSON, Forrester (1970) observed subsurface oil particles in Chedabucto Bay ranging form 0.1 mm to 2 mm. These particles, which were collected in a Clake-Bumpus plankton sampler, were observed down to 50 metres below the surface throughout the Bay except in the vicinity of Guysborough. Concentrations were estimated by dissolving the collected oil in chloroform and comparing the colour of this solution with that of a series of standards. The maximum concentration observed was about 0.02 ppm, and the concentration generally decreased with depth. Particles were also found outside the Bay in a 'tongue' about seven miles wide stretching eastward from the mouth of the Bay for a distance of almost 45 miles.

During the second phase (February 24 to March 7) of the DAWSON cruise, it was found that the distribution of oil in the Bay had not greatly changed, except that oil particles were now found in the Guysborough area. However, the 'tongue' of particles previously observed to the east of the Bay had apparently disappeared. A flow of oil particles was then detected moving southward out of the Bay. Sampling showed that a band of particles about 5 to 15 miles wide extended southwestward along the coast from Cape Canso to Chedabucto Head and beyond. Forrester (1970) estimated that the band of particles was moving at a speed of about four miles per day. By about the middle of March the phytoplankton had come into full bloom, and it was no longer possible to distinguish oil particles against this background.

A later study (March 9-13th) was organized (Kranck and Sheldon, 1970) to investigate the concentration and sizes of dispersed particles of less than 100 microns, in order to assess the possible effects of oil on the first stages of the marine food chain. A Coulter particle counter was employed, and it was hoped that if the oil particle concentrations were large, they would register as a distinct anomaly in the natural particle spectra.

A grid of 32 stations was established. Samples of suspended particulate matter in the 1 to 100 micron range were collected from a complete range of depths. The results to date indicate a two-layer system in the open waters of Chedabucto Bay. The phytoplankton bloom caused a concentration in the 30 to 70 micron range

between the surface and about 50 metres, with a pronounced peak at 50 microns. In this upper layer, total particulate concentrations are 1.40 to 0.50 ppm, with a minimum of about 0.26 ppm at 50 metres. The material in the bottom layer, i.e. below 50 metres, ranges from 1 to 60 microns, and concentrations increase downward with values as high as 0.50 to 0.60 ppm near the mouth of the Bay. The two-layer structure is not found in the Canso Strait and Lennox Passage areas. Filters from samples were abundant in shiny, greasy-looking particles.

From the samples taken in the Bay, small oil droplets were found in the filtered material, but these were not distinguishable from plankton bloom and mineral matter in the particle spectra. By the end of April the plankton bloom had almost receded, and cursory examination of filtered samples indicated much lower particulate concentations. Oil droplets actually appeared to be more abundant. Several samples below oil slicks showed an increased oil droplet concentration, but other small black irregular-shaped particles were also observed. These particles were identified (Langer 1970) as a cinder-type material, being about 90% carbon.

An attempt was made to measure the concentration of the oil particles by extracting the filters with hexane and analyzing the extract using an Aminco-Bowman fluorimeter. Four samples showed concentrations of oil from 0.01 to 0.06 ppm in sea water; the lower limit of detection being 0.01 ppm.

As it was considered desirable to develop a reliable technique for measuring particulate oil concentration for use at sea, Levy (1970) undertook the development of a shipboard method involving the extraction of the oil in n-hexane after filtration of the water sample and the measurement of the ultra-violet absorbence of this solution. After considerable laboratory testing, the system was used during the cruise of the "SACKVILLE" (April 17 to May 8). Particulate oil concentration of 0.016 to 0.04 ppm were observed at various points in Chedabucto Bay. Levy also observed oil in the filtrate i.e. in the solution.

Although it has been established that oil does exist disposed in the water column, with particulate concentrations as high as 0.06 ppm over a considerable area, it has not yet been established whether this mechanism is significant in the ultimate dispersion of oil at sea. Furthermore, due to the very complex nature of the problem, it is not possible to comment on the effect of the dispersed oil in the marine ecosystem.

3.3 Oil in Icy Waters

During February and March many areas of the Bay were covered with ice, particularly the less open areas such as Inhabitants Harbour and Lennox Passage. The shoreline was generally covered with snow and lined with slush and pan ice. Lagoons were intermittently frozen. Some observations of the interaction of oil and ice have been made in the field. Simple freezing experiments have also been performed in the laboratory.

3.3.1 Lagoons

Certain lagoons had trapped oil which was later covered by ice. For example, on February 14 in Janvrin Lagoon, oil was measured to a depth of greater than 10 cm (Thomas, personal communication, 1970). Overnight the temperature dropped to 5° F and the lagoon froze with a slurry of ice and water freezing over the oil. The oil did not mix into the ice, and where the lagoon had been frozen over before the oil entered, there was an ice-oil-ice layering of up to six inches in oil thickness. Oil trapped in such a manner ramained black and fresh looking.

3.3.2 Oil in Snow and Ice

The contamination of ice and snow-covered shorelines occurred in the same manner as oiling of bedrock (see Section 3.4.3, p.23) Thick layers of oil first covered the ice and snow and then the underlying rock and water as melting occurred. Where ice was forming as the oil came ashore, two types of mixtures were deposited. The first was a coarse crystalline ice, unconsolidated and light brown in colour. There were small oil particles around the ice crystals and very small ones within the ice. Volumetric analysis of several samples from Janvrin Island on March 3 yielded values of 1% and 5% oil. The second mixture consisted of consolidated lumps with contained oil lumps. One sample of this type contained 7% oil. Occasionally there were oil droplets on top of the ice. The oil, because of its black colour, would absorb sufficient solar radiation to melt its way down into the ice. Bulldozing of oiled ice and snow was attempted, but was discontinued because the oil content was generally under 5%.

3.3.3 Oil and Shore-Fast Ice

There were large areas of shore-fast ice in Lennox Passage and Inhabitants Harbour, the extent of which increased from early February and reached a maximum coverage around March 1. An oil reconnaissance chart for this area on March 1 is shown in Figure 3.2 (Barber, personal communication, 1970), in which the position of the ice front on earlier occasions is also shown. After this date the ice retreated; Lennox Passage became open on March 31, and Inhabitants Harbour was ice free by April 16.

In Lennox Passage the first mile of the ice plug to the west of the bridge had formed prior to any oil contamination (Markham, 1970). By mid-February occasional heavy pools of oil were reported against the ice front, and as the ice continued to grow, a quarter to half mile section of contaminated ice was formed. The length of the plug was reported to be 1.5 miles on February 11 and about 7 miles by March 1. The ice thickness was up to 6-8 inches but even this was partly snow. On about March 2 it was predicted (Markham, 1970) that the duration of this ice cover would be about 5-10 days. However, subsequent cool weather, several snowfalls and the installation of the causeway at the bridge delayed the break-up and clearing of ice until the end of March.

For the Inhabitants Harbour area the ice front was not reported on oil reconnaissance charts until February 20. Earlier, on February 9, the area was reported almost ice-free; there was very little contaminated shoreline and only a few irridescent slicks. At no time were old dirty ice fronts reported in Inhabitants Harbour. On February 13, following SE winds on the 11th and SSW winds on the 12th, a heavy slick was reported against the south shore of Evans Island and along the northeast shore of Rabbit Island which caused repeated oiling of the shoreline.

As the ice grew, oil pools were seen forming along the ice front, even as late as March 6 (see also Section 3.3.5, p.21).

3.3.4 Laboratory Freezing Experiments

A series of laboratory freezing experiments were conducted (Lewis, 1970) as follows:-

(l) Unidirectional freezing from the surface was applied to a tank of sea water with a 1/4 inch layer of Bunker C floating on the surface. The tank was put into a cold room at -35° F and a downward blast from an air blower simulated wave action. Next day a layer of thick oil was found on top of a very irregular sea ice surface. No appreciable mixing had occurrred and only a few ice crystals had collected in the irregularities of the water-oil interface.

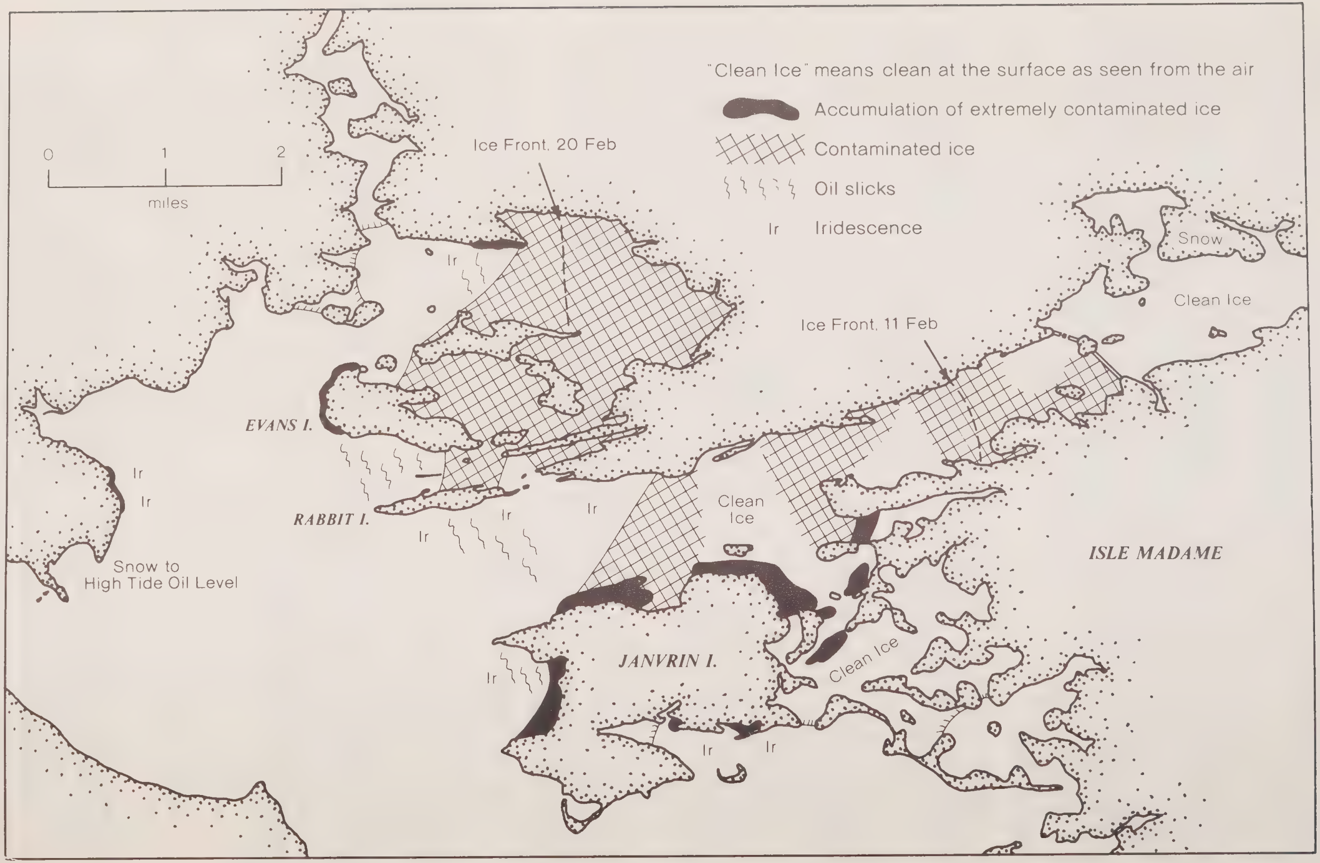


Fig. 3.2. Oil reconnaissance chart of Lennox Passage, Inhabitants Bay area, March 1, 1970 showing the extent of the ice cover.

(2) A mixture of oil and water was shaken up in a jar and placed in the freezing section of a refrigerator. The oil separated out before freezing occurred, producing a layer of oil on top of the ice.

(3) Bunker C and sea water were mechanically stirred in a cold room until the water temperature reached the freezing point. Unidirectional freezing was permitted to take place for 67 hours at an ambient temperature of -30° F. A layer of emulsified oil three inches thick froze over the ice, which contained oil inclusions, too. The section below this oil layer consisted of 56% oil at a depth of 1 inch, 33.3% at 2 inches, 27.5% at 3 inches, 6.4% at 4 inches, and only a trace at 7 inches, respectively, from the ice-oil interface.

3.3.5 Oil under Ice

While no observations of oil under ice were made, it is suspected that oil was trapped under the ice and released when the ice cover melted. Observations by Wicks (1970) on the behaviour of oil against a boom may provide an analogy to an ice plug. He has concluded that booms (see also Section 6.2, p.53) fail either by the tearing of oil drops by the current from the gravity wave region at the head or upstream end of the slick, or by the draining of oil from the region adjacent to the boom, down and around the boom skirt. The 8-inch thick ice plug in Lennox Passage could be regarded as an 8-inch boom followed by a long flat plate. With currents often in excess of 2 ft/sec, considerable amounts of oil could be trapped under the ice sheet and held there by hydrostatic pressure and frictional drag. However, preliminary results from observations in the Gulf of St. Lawrence (Johannessen, 1970) indicate a logarithmic current profile under the ice. Roughness lengths were found to vary from 3.7 inches for very rough ice to 0.3 inch for smooth ice. Thus an oil layer of less than one-half inch would lie near the base of a laminar flow layer where the drag force is small. The viscosity of the oil emulsion is 10^4 to 10^5 times that of water at 0° C, and a rough estimate of oil velocity would therefore be 0.4 inch/day. In other words, oil could remain trapped under the ice, even in large currents. The lack of field observations indicates an obvious need for more research into the problems of oil under ice.

3.3.6 Measurement of Oil under Ice

With the lack of a simple method for measuring oil under ice, a device called the "clapper" was invented (Sheffer, personal communication, 1970). The "clapper" consists of two 5-foot lengths of 1 x 2 inch board, hinged together at one end. With the faces held tightly together, the hinged end is lowered through a hole in the ice extending past the bottom of the oiled layer. The faces of the boards are then separated allowing the oil and water to flow freely between the boards and to come into contact with the boards. The boards are then closed tightly again, squeezing out the oil and water trapped between them, and retracted from below the ice. When the boards are opened again, the thickness of the oil is clearly visible as a black streak where it has oiled the boards. While this improvised method appeared to be useful, the break-up of the shore-fast ice shortly after did not permit any oil-under-ice measurements with this technique.

3.4 Shoreline Contamination

3.4.1 North Shore

Aerial reconnaissance indicated that almost all of the coastline on the north side of Chedabucto Bay was oiled at one time or another in February (see Figure 3.1, p.16). The most heavily polluted areas were the south shores of Janvrin, Crichton, Jerseyman and Isle Madame Islands and the south shore of Petit-de-Grat Island, lying within five miles of Cerberus Rock. Between February 27 and March 13, geological observations were conducted (Asthana and Marlowe, 1970) in the Isle

Fig. 3.3 Oil contamination of bedrock shoreline, western end of Durell Island, March 24, 1970.

Madame-Petit-de-Grat area, most notably "McDonald's Beach", the eastern half of Deep Cove, the shoreline between Cape Auget and Marache Point, beaches between Arrow Point and Jersey Point and Pondville Beach. The contamination of these areas has been extensively photographed.

3.4.2 Western and Southern Shore

Aerial reconnaissance showed varying amounts of oil on most of the west and south shores, with areas near Canso and southward of that heavily oiled. Geological observations have been conducted in this area (Schafer, 1970, and Drapeau, 1970). The degree of oiling increased from Half Island Cove to the mouth of Chedabucto Bay near Canso. Drapeau investigated and photographed the oiling at Halfway Cove, Half Island Cove, Fox Bay, Durrell Island, Glasgow Head and Black Duck Cove.

3.4.3 Nature and Behaviour of Oil Attached To Shore Material

Conclusions regarding the nature and behaviour of oil in relation to the coastal morphology and sediments (Asthana and Marlowe, 1970, and Drapeau, 1970) can be summarized as follows:-

(1) Upon reaching the shoreline, the oil generally adhered to it, much of it at the high water mark because of tidal and wave action.

(2) Floating oil, striking the shoreline, behaved differently on the different types of shore material; namely (i) bedrock, (ii) boulder beaches, and (iii) sand and gravel beaches.

(i) Oil striking bedrock coated the shoreline uniformily and tenaciously, and was largely confined to the intertidal zone (Fig. 3.3, p.22). Although it does not float off when submerged during the tidal cycle, the oil does form an intermittent coating that is constantly moving. When exposed at low water, it flows into crevices and down the shore.

(ii) Oil adhered uniformly to boulder beaches and often completely covered individual boulders (see (Fig. 3.4, p.24) Here, too, oil does not float off when submerged but does flow off. It was observed (Pew, personal communication, 1970) that heavy oiling tended to stabilize cobble beaches.

(iii) Oil droplets and blobs on sand and gravel beaches, observed during investigations in late February and early March, were largely confined to the surface of the sediment. They did not entrap large quantities of sediment, but rather behaved as discrete sedimentary particles (see Fig. 3.5, p.25). At this time, air temperatures were in the 20 to 27° F range. Oil particles acquired a surface coating of sand grains, which effectively prevented further adhesion of sedimentary characteristics. Later observations revealed small amounts of oil as far as three feet below the surface, but this was caused by the normal processes of erosion and redeposition over many tidal cycles.

Instances were found, however, where oil thoroughly permeated gravel beds to a depth of 12 to 18 inches (see Fig. 3.6, p.26). In even very weak sunlight, oil was seen to flow slowly down local slopes. Where sediment and oil were mixed, oil gathered under the influence of gravity and flowed out of the sediment and down the gradient across the surface of the foreshore. Intertidal gravel deposits that had become permeated by oil formed ephemeral ledges, but the faces of such ledges were seen to crumble rapidly under the influence of gravity and sunlight.

Fig. 3.4 Oil contamination of a boulder beach, Black Duck Cove, March 24, 1970.

Fig. 3.5 Oil contamination of a sandy beach near Cape Auget, March 2, 1970.

Fig. 3.6 Permeation of oil into gravel beds, Indian Cove, March 24, 1970.

3.4.4 Coastal Geodynamics Study - Crichton Island

A study is continuing on the relationships between geodynamics and the behaviour of oil on the shoreline. A test beach was established on the southeastern side of Crichton Island. This site was chosen because (i) it had been heavily oiled, (ii) the shore zone is composed of all the types of material found in the area, and (iii) the island is not open to the public, yet it is accessible for scientific studies (with the kind permission of the owners). It is an ideal location for the correlation of coastal geodynamic observations with coastal oceanographic data, meterological information, the distribution of offshore sediments and suspended matter, and biological information (nearshore and intertidal). The observations will be carried out for short periods each month for at least one year.

Emphasis has been placed on photographic techniques. Time lapse photography with a 16 mm movie camera has already been used to record the flow of oil off bedrock surfaces (Belanger, personal communication, 1970), and will be used to study the effects of a tidal cycle upon the micro-morphology and sediments in the intertidal zone. From a reference network of aluminum poles, repeated still photography will be taken to record precise changes in specific oil patches, oiled boulders and bedrock, and micromorphology. The reference network of aluminum poles has been arranged on the back and foreshore along one mile of shoreline. A precise map of the area will be constructed. In addition, profiles of the shore will be repeatedly measured in order to monitor precisely any changes in the sediment and microrelief of the beach.

Wave refraction patterns will be computed for the correlation of the geodynamics of the shore with coastal oceanographical data. Current and wave observations have already been taken (Neu, 1970) and are presently being processed and analyzed.

3.5 Bottom Sediments

It was found that oil in particulate form which had picked up sediment behaved as a sedimentary particle. A regional study was thus initiated on the distribution, nature and oil content (if any) of the bottom sediments in Chedabucto Bay.

Bottom sampling and echo sounding data, both from earlier studies prior to the ARROW grounding and from recent cruises of CSS DAWSON, CNAV SACKVILLE and CNAV FORT FRANCIS, indicate a nearly continuous but thin sediment cover of gravel, sand, mud and glacial till on the floor of the Bay. Generally, gravel and sand are predominant in water depths of less than 20 feet and on topographic highs or low-rising elevated areas offshore.

Fine sediments (muds) occur in the deeper waters of the submarine valleys in isolated near-shore depressions, and at the head of the numerous bays and inlets. Most of the fine sediments have been deposited recently in response to the present current regime in the Bay, and derive mainly from the reworking of glacial till. Most glacial till is now buried by recent marine sediments, but is also found on offshore topographic highs.

Chemical analysis of 32 bottom samples from the CSS DAWSON cruise showed oil concentration of 2 to 2.5 ppm in four of the samples. These samples came from Arichat Harbour, Fox Bay and a location 2-3 miles off Guysborough. The presence of oil at two of these stations was also confirmed by a later cruise of CNAV FORT FRANCIS. The source of these low concentrations of oil is not clear, since there is also a natural occurrence of oil in the sediment. In addition, we have pointed out in Section 3.2, p. 17, the difficulty in analyzing such low concentration of oil. Further monitoring of the sites where oil was found and analysis of sediments from other locations is continuing. This will help to establish the fate of the oil and the biological significance of oil in the sediments.

3.6 Oil on Sable Island

In mid-February after reports had been made that the shores of Sable Island had been contaminated by oil (possibly by oil that had drifted southeastward from Chedabucto Bay), a brief inspection of the eastern end of Sable Island was carried out by Loring (1970) and McLean (personal communication, 1970) from Scientific Coordination.

Sable Island lies approximately 100 miles southeast of Chedabucto Bay and is essentially a crescent-shaped, low-lying sand bar. It is roughly 20 miles long with a maximum width of one mile and has wide sand beaches which are kept in constant motion by heavy surf and wind action.

On March 18, 1970, a two-hour helicopter reconnaissance was carried out along the north shore and the east spit. Brown and black discolourations in the sand (which were later proven to be due to oil) were seen on the north shore from the air. Oil contamination extended along all of the north shore in the intertidal zone in the form of fresh looking black blobs, 3 to 18 inches in diameter.

The spit at the eastern tip of the island was inspected on foot. On the central and south sides of the spit, about 10 to 15% of the surface area was oiled in patches ranging from 10 inches to 50 feet, apparently formed by oil impregnation of the sand to a depth of about 0.2 inch. Coring and digging revealed that the oil was also interbedded in places with clean quartz sand. These formed layers 1 to 5 inches thick between oil horizons to a depth of at least three feet due to redeposition. On the surface, the oil-impregnated sands were stable while the clean sands were constantly shifting. Differential erosion has resulted in a characteristic mircorelief with alternating highs of oil-impregnated sand and lows of clean sand. Sand-coated oil was also present as 1 to 2-inch lumps in a band 20 to 30 feet wide for about one-half mile along the north shore above the high tide level.

Black fresh-looking oil blobs containing up to 25% water were present in the intertidal zone at the end of the spit and along a 10 to 20 feet band on the north shore extending for about ten miles. Analysis of oil samples indicated that the oil had the same origin as the ARROW oil (see Table 4.4, p.38).

The sands of Sable Island are in constant motion, and a second trip to the Island is planned for July to re-examine the oiled areas and to assess the amount of self-cleaning that may have occurred.

4. BUNKER C OIL AND THE SEA WATER-OIL EMULSION

4.1 Bunker C Oil

4.1.1 The Manufacture of Bunker C Oil

The oil carried by the tanker ARROW was a heavy residual fuel oil of the type commonly known as "Number 6 fuel oil" or "Bunker C oil" and was made at Amuay refinery, Venezuela.

In the initial stages of refining, crude oil is subjected to a process of distillation to separate the more valuable components, or fractions, of the oil. The oil is first distilled at atmospheric pressure to obtain the light components, for example, those which constitute gasoline or kerosene. The least volatile portion of the oil leaves the bottom of the distillation column at a temperature of about 700°F and is then fed to another distillation column which operates under vacuum and where further separation takes place. The extremely involatile residue, commonly known as pitch, which leaves the bottom of this column, is used as the basis of either Bunker C oil or asphalt.

In order to modify the properties such as viscosity or sulfur content, to those required by the users of Bunker C, the pitch is blended with a more volatile fraction of "flux". In the case of the oil carried by the ARROW, the flux was some of the residue leaving the atmospheric distillation column. It is also customary to add residues from distillation of products of the catalytic cracking process. However, as no catalytic craker exists at the Amuay refinery, the ARROW oil did not contain these residues.

4.1.2 Physical Properties

Perhaps the most significant physical properties of an oil, from the point of view of those interested in oil spills, are volatility, specific gravity, viscosity and surface tension. Bunker C oil has very low volatility so that the loss of oil (due to evaporation) after a spill will be minimal and combustion of floating oil is exceedingly difficult. Its specific gravity tends to be close to that of water, enhancing its tendency to mix with water. The viscosity is very high, making pumping and other forms of handling extremely difficult and the tendency to form stable water-in-oil emulsions is also increased.

The "pour point" of the ARROW oil was 30°F. This is the temperature below which the oil does not flow freely (under specified test conditions) because of the crystallizing out of some of the components of the oil. This has significance to the Chedabucto Bay problem in that the sea temperature at the time of the spill was below 30°F and therefore once the oil attained the temperature of the sea it had a semi-solid consistency. This diminished the rate of spreading and resulted in an increased tendency for slicks to break up. It also rendered emulsification of the oil with chemicals much more difficult.

Table 4.1 below shows physical properties of the ARROW oil as reported in the inspection analysis carried out at Amuay refinery (Belshaw, personal communication, 1970).

TABLE 4.1

INSPECTION ANALYSIS ON THE CARGO OF THE "ARROW"

Ash, total	0.08 wt %
Ash (water soluble)	0.04 wt %
Carbon Residue	12.00 wt %
Gravity	15.5 API/60°F
Pour Point (upper)	30°F
Sediment (B.S.W.)	1.00 wt %
Sulfur	2.24 wt %
Viscosity	275 SSF/122°F

NOTE: (a) 15.5°API/60°F 0.963 S.G. 60°F/ 60°F

(b) 275 SSF/122°F 545 centipoise at 122°F

4.1.3 Chemical Composition

A residual fuel oil is an extremely complex mixture and less is known about the composition of residual material than any other petroleum fraction. The elements present are carbon, hydrogen, sulfur, nitrogen, oxygen, and trace metals such as vanadium, nickel, iron, etc. The types of compounds present can be classified into three semi-arbitrary fractions called oils, resins, and asphaltenes, based on the solubility of the oil in various solvents. This classification and the elemental analysis for the ARROW oil are shown in Table 4.2. The analysis was made at the Fuel Research Centre, Mines Branch, Department of Energy, Mines and Resources, Ottawa.

The oil fraction of a residual fuel oil, representing about 71-75% of the composition of the ARROW oil, is known to contain high molecular weight (above 400) paraffins, isoparaffins, cycloparaffins, mono-aromatics, polyaromatics and sulfur compounds, such as benzothiophene and dibenzothiophene derivatives (Hunt and O'Neal, 1965).

Due to the inefficiencies in the distillation process and to the relatively more volatile nature of the flux, lower molecular weight paraffins will also be found.

TABLE 4.2

COMPOSITION AND ELEMENTAL ANALYSIS OF OIL FROM "ARROW"

Oils	73.10 wt %	Sulfur	2.21 wt %
		Carbon	86.13 wt %
Resins	16.31 wt %	Hydrogen	11.56 wt %
		Nitrogen	0.39 wt %
Asphaltenes	9.28 wt %	Oxygen	1.25 wt %
		Vanadium	272 ppm
Unrecovered	1.31 wt %	Nickel	35 ppm

The polyaromatic portion consists mainly of naphthalene derivatives with lesser amounts of larger condensed ring aromatics and is a possible source of carcinogens. Studies by the Medical Research Division of Esso Research and Engineering Co. indicated that fuel oils from refineries which do not have catalytic cracking or visbreaking facilities, such as Amuay, contain fewer polynuclear aromatics (Berkhoff, personal communication, 1970). Analysis for benzo-a-pyrene in the

ARROW oil has so far yielded negative results (Monkmann, personal communication, 1970; and Zitko and Carson, 1970).

The analysis of the resin fraction, representing about 15-18% of the ARROW oil, is an extremely intractable problem and very little is known about its composition and structure. The compounds present appear to be mostly large heterocyclic molecules with an average molecular weight of about 930 (Hunt and O'Neal, 1965).

The asphaltene fraction, represented by about 8-10% of the ARROW oil, is also an intractable analytical problem. Analysis using a mass spectrometer indicates the presence of heterocyclic ring structures. It would appear that asphalt is mainly composed of systems of up to six condensed aromatic rings, interconnected by short chains (Hunt and O'Neal, 1965). Estimates of the average molecular weight vary from 900 (Hunt and O'Neal, 1965) to 3,500 (Corbett, 1969).

Various metals occur in trace quantities in crude oil and hence in residual fuels, the ratio of the concentration of vanadium and nickel in an oil being accepted as a means of identifying sources of oil pollution (Institute of Petroleum, 1970). The concentrations of vanadium and nickel in the ARROW oil are given in Table 4.2 (p. 35). The metals appear to occur mainly in association with nitrogen in the form of porphyrins (Hunt and O'Neal, 1965).

4.2 Emulsion of Bunker C Oil and Sea Water

4.2.1 Emulsion of Sea Water in Oil

Although the fact that petroleum stocks form very stable water-in-oil emulsions has been known for many years in the petroleum industry, it was not until the TORREY CANYON incident that the formation of these emulsions became a focus of considerable attention in connection with marine pollution by oil. The emulsion formed by the Kuwait crude oil carried by the TORREY CANYON, termed "chocolate mousse", consisted of as much as 80% water (Great Britain, Cabinet Office, 1967). Water-in-oil emulsions were also noted after the wreck of the WORLD GLORY off the coast of South Africa in 1968 (Beynon, 1969) and during the Santa Barbara Channel incident where water concentrations up to 50% were encountered (Battelle Memorial Institute, 1969).

The reason for the extreme stability of these emulsions is not yet clear. Berridge, Thew and Loriston-Clarke, 1968, concluded that the stabilization was due to complex chemical components in the non-volatile residues, particularly asphaltenes and possibly porphyrins. They concluded that bacterial activity, marine organisms and suspended solid matter were not significant or essential factors as has been suggested by other workers (Berridge et al, 1968, and Davis, 1968).

The Bunker C oil spilled from the ARROW also formed stable emulsions. The properties of Bunker C are such that clean-up by means such as burning, etc., is extremely difficult, and the formation of these emulsions aggravates the problem. The presence of water in the oil, either directly or by the consequent increase in the viscosity, prevents burning, makes the use of dispersants less effective, hinders absorption by agents such as peat, etc., and hinders pumping and other forms of handling.

The "stiffness" of the emulsion, however, does facilitate manual pick-up methods and the rate of contamination of sandy beaches is probably lessened as there is less inclination for the oil to flow through the sand.

4.2.2 The Concentration of Water in the Emulsion

Three surveys were conducted to assess the range of water contents at various locations in Chedabucto Bay. No pattern, either based on geography or time, was observed. A typical selection of the results is shown on Table 4.3. The concentration

of water was determined by the Dean and Stark method A.S.T.M. E123, that is by adding toluene to lower the boiling point of the mixture and distilling over the water with the toluene. The method, A.S.T.M. D196, based on centrifuging the toluene-emulsion mixture, was found to be unsatisfactory. The measurements were carried out at the Dockyard Laboratory of the Defence Research Establishment Atlantic and at the Atlantic Oceanographic Laboratory. It will be noted that the concentrations reported are typically well below the 80% figure observed during the TORREY CANYON incident and in some other instances the values were below 30%.

TABLE 4.3

CONCENTRATION OF WATER IN SAMPLES OF WATER-IN-OIL EMULSION COLLECTED AT VARIOUS LOCATIONS IN CHEDABUCTO BAY

Location of Sample Point	First Survey	Second Survey	Third Survey
Heath Head to Petit-de-Grat	53% water	33% water	37% water
Cape Auget, light station	43%	43%	42%
Durell Point, Durell Island	34%	41%	46%
French Point, Durell Island	47%	35%	42%
Fox Island Main	36%	37%	42%

First Survey March 5, 1970, to March 7, 1970

Second Survey March 31, 1970, to April 3, 1970

Third Survey June 4, 1970, to June 5, 1970

It was not possible to obtain good estimates of the time for the water concentration to reach a stable value subsequent to the spillage of the main cargo. However, an estimate was obtained from other information. On March 25, 1970, part of the ARROW's own fuel supply, also Bunker C, was spilled and samples taken on March 28, 1970, just after a slick came ashore, showed a water concentration of from 31% to 35%. On April 19, 1970, as a consequence of the sinking of the PATRICK MORRIS off the coast of Nova Scotia, a slick of Bunker C oil was released onto the surface of the sea. A sample of this slick, taken on April 21, 1970, was found to contain 21% water.

From these two observations it was concluded that the exposure time in the sea necessary to increase the water content to over 30% was of the order of three days. This time will depend very much on the sea state. It was also apparent that the oil, once ashore, continued to pick up water due to the pounding of the surf until a stable maximum concentration was reached. This view is supported by the fact that the performance of peat moss as an absorbent for shore-bound oil deteriorated rapidly with the passage of time. Burning, originally successful in dealing with freshly-beached oil, also became impossible as time progressed (see Sections 6.1, p. 51, and 6.5, p. 58).

4.2.3 The Viscosity of the Emulsion

It was very obvious that emulsification led to a marked increase of viscosity over that of the original oil. To examine this effect in more detail, studies were carried out in the Chemical Engineering Department of Nova Scotia Technical College (MacKay, 1970, and Richards, personal communication, 1970). Measurements of viscosity were made using a Brookfield variable shear viscometer on a sample of typical Bunker C oil, assumed to represent the cargo of the ARROW, and on a sample of the emulsion collected at Chedabucto Bay containing 40% water. The viscosity on emulsification was found to increase from 700 poise at 32°F for the pure oil to almost 30,000 poise. A series of experiments was later conducted to

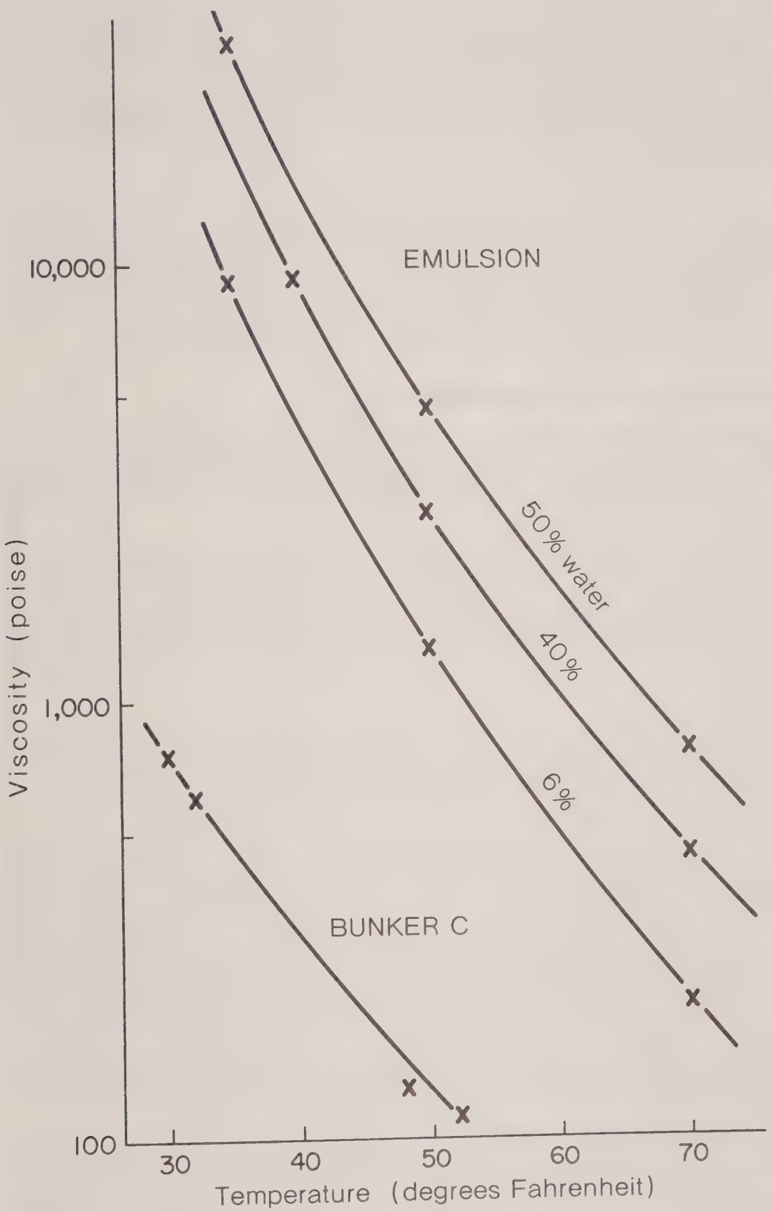


Fig. 4.1 The effect of temperature and water concentration on the viscosity of Bunker C and Bunker C - water emulsions with 6, 40, and 50% water content.

investigate the effect of the water concentration of viscosity on synthetic emulsions of Bunker C and sea water. The reason for using synthetic emulsions was twofold, namely to provide more control over the water content, and because most of the natural emulsions contained seaweed and other extraneous matter which were liable to interfere with the operation of the viscometer. The results of this study are presented graphically in Figure 4.1.

It was considered possible that the emulsion might be sufficiently non-Newtonian to make the viscosity very dependent on shear, and measurements were therefore made at constant temperature over the range of shear rates at which the viscosity measurements had been made. The viscosity was indeed found to decrease with shear rate but the effect was small enough not to affect the conclusions to be drawn from Figure 4.1 as the values indicate there are the average values over the appropriate range of shear rates.

In the course of these studies if was found that the repeatability of viscosity measurements, in spite of careful attention to techniques, was often poor. It is probable that the irregularities are due to the complex nature of Bunker C oil. The oil, containing as it does many components which are mutually insoluble, lends itself to the formation of colloidal structures, especially at low temperatures and, therefore, the viscosity will tend to be dependent on the history of the sample.

4.2.4 The Effect of Emulsification on the Combustion of Oil

One obvious method of disposing of the emulsified oil which was deposited on the shore was to burn it and a series of experiments were therefore carried out at the Atlantic Regional Laboratory of the National Research Council to ascertain whether this was feasible (Caines, Dobson and Masson, 1970)

It is known that Bunker C oil can tolerate a certain amount of water and still burn. Lawrence and Killner (1948) reported that emulsions of 10% sea water in fuel oil were burned with no apparent difficulty in ships' boilers after preheating and it was decided to attempt to establish whether typical emulsions could be burned and if so, what would be the temperature at which the oil had to be heated to maintain combustion.

For reference purposes a sample of Bunker C oil alleged to be similar to that carried by the ARROW was obtained from the Imperial Oil refinery, Dartmouth. The flash point of this material was found to be 210°F and the fire point, that is the temperature at which combustion was sustained, was found to be 328°F.

Tests were conducted on a 30% synthetic emulsion of sea water and Bunker C and a natural emulsion collected from Durell Island, Chedabucto Bay, and containing about 40% water and sediment. It was found that the emulsion could not be heated in any enclosed vessel as extensive foaming took place at about 110°F which prevented any further experimentation. Tests on the Durell Island Emulsion were then carried out in an open dish (Petri) placed on a hotplate. The temperature was increased slowly and the water driven off with some slight frothing. Although fumes began to come off at 350°F, the flash point was not reached until 600°F, and ignition could not be maintained until above 900°F. Even at this temperature ignition was not complete and a black, tarry crust would form on the pool of oil and extinguish the flame. When this crust was broken, the unburned oil could be relit.

It was observed that the presence of foreign matter, e.g. peat moss or cardboard, assisted combustion by providing a wick effect. This wicking mechanism is relied upon in the use of "Sea Beads" (see Section 6.5, p. 58) which are described elsewhere in this report. It was also noticed that rapid heating caused the oil to burn more readily.

Obviously, the effect of emulsification of the oil, even with the addition of flame carriers like peat moss, makes disposal of the oil by burning far more difficult.

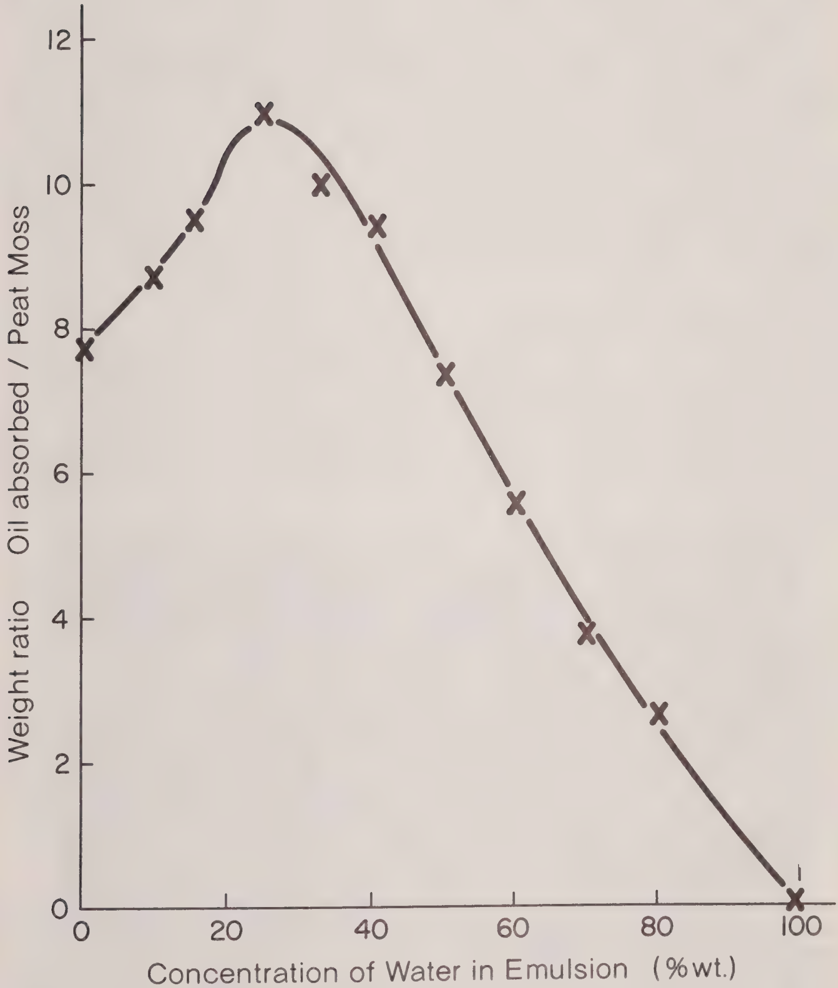


Fig. 4.2 The effect of water content of the water-in-oil emulsion upon the absorption of oil by peat moss.

The main reason is probably due to the fact that when the water is driven off, the volatile constituents of the oil are steam distilled out leaving a material of extremely low volatility and hence, combustability. Furthermore, in the case of natural emulsion some of the volatile constituents have probably already been lost by evaporation. Also, large amounts of heat are required to replace the latent heat lost during the evaporation of the water. Based on the results of this work, the following features necessary for sufficient combustion are suggested:-

(1) Preheating of the emulsion, initially at least, to 900°F - 1000°F.

(2) Sufficient surface area to prevent choking of the burner due to foaming.

(3) Adequate provision for excess air in view of the fact that water vapour will tend to "blanket" the flame.

These requirements would appear to rule out the possibility of burning emulsion as it lies on the shoreline, that is without picking it up.

Preheating can be accomplished by injecting the emulsion into the flame of a sophisticated burner such as a fluidized bed burner of a modified asphalt drier, both of which would have sufficient surface area and air access to satisfy conditions 2 and 3. Both these burners would be especially able to handle the large amounts of sand and small rocks which would be associated with the emulsion if recovered from a shore. At a less sophisticated level of operation, that is disposal on the beach, sufficient heat might be obtained by mixing the emulsion with large quantities of peat or wood. These combustibles, if in sufficient quantity, would supply sufficient preheat for the emulsion to attain and maintain the ignition temperature.

4.2.5 The Effect of Emulsification on the Absorption of Oil

Laboratory work at the University of Sherbrooke (Coupal, 1970) suggested that peat moss would be an effective absorbent for cleaning up Bunker C oil spills (see Section 6.1, p. 51). Field trials (Coupal, 1970) at Chedabucto Bay on February 18, 1970, confirmed this suggestion, but later trials (February 25) showed that the peat moss had declined in its ability to absorb oil and that it could no longer be considered effective. It was suggested that this decline was due to the emulsification of the oil and to examine this point, tests were carried out at the University of Sherbrooke (Coupal, 1970).

It was found that the quantity of oil absorbed per gram of peat moss, when plotted against water concentration of the emulsion, went through a maximum at around 25% water (see Figure 4.2, p. 35). The results of the field trails could, therefore, be explained by postulating that during the earlier trial the water concentration in the emulsion was around 25 to 30% and had risen to 40 and 50% for the later trial. Another possibility is that the effectiveness is reduced as a direct consequence of the increase in viscosity brought about by emulsification. This effect would not be shown up during the laboratory experiments as the emulsion was intimately mixed mechanically with the peat, a procedure not employed during the field trials.

4.2.6 Flow Behaviour of the Emulsion

Experiments to determine the likely flow behaviour of the emulsion were carried out at the Atlantic Regional Laboratory, National Research Council (Caines and Masson, 1970). Strips of emulsion were deposited on panels of glass and transite (to give an effect of surface roughness). The panels were held either vertically or at an angle of 45 degrees and the rates of flow of the emulsion were studied at 39°F, 70°F and 150°F, the latter temperature being the highest surface temperature likely to be experienced. It was found that the oil emulsion did not flow on an even front but in a series of tails into which the bulk of the emulsion drained. There was no striking difference of behaviour in the flow over the two types of

surfaces. It was concluded that under normal summer temperatures, the emulsion would drain off sloping surfaces within a few weeks leaving a thin residual layer. In these experiments the effect of "thickening" of the oil and the consequent effect on flow due to oxidation into asphaltic type material was not considered.

4.2.7 The Spreading Characteristics of the Emulsion

Investigations into the effect of emulsification on the spreading characteristics of Bunker C oil were carried out in the Chemical Engineering Department of Nova Scotia Technical College (Richards, 1970). Surface tensions, that is for sea water-air, oil-air, emulsion-air, and the interfacial tension oil-sea water, were measured on a du Nouy tensiometer for various temperatures. From these values the spreading coefficient, that is the tendency to spread, was calculated using the expression:-

$$S \; Y_2 - Y_1 - Y_{12}$$

Where S is the spreading coefficient

Y_2 is the surface tension of sea water
Y_1 is the surface tension of oil or emulsion
Y_{12} is the interfacial tension (oil-sea water or emulsion-sea water)

The spreading coefficient was found to decrease as the water concentration increased, thus emulsification will decrease the tendency of oil to spread.

It was noticed in the course of the experiments that if a drop of oil or emulsion were placed on clean sea water in a confined vessel, no spreading took place, the material remaining as a lens floating on the surface. When the lens was removed and the surface tension of the sea water remeasured, it was found to have fallen to about 61 dynes/cm from the usual figure of about 75 dynes/cm. This indicates that a surface active material was "leached" from the oil to spread as an invisible layer, possibly a monolayer, over the surface thus preventing the spreading of the bulk of the oil. This mechanism explains why small non-spreading lenses of emulsified oil could be seen on rock pools on the shores of Chedabucto Bay, while it is known that similar sized quantities of oil spread rapidily on the open sea to form irridescent films.

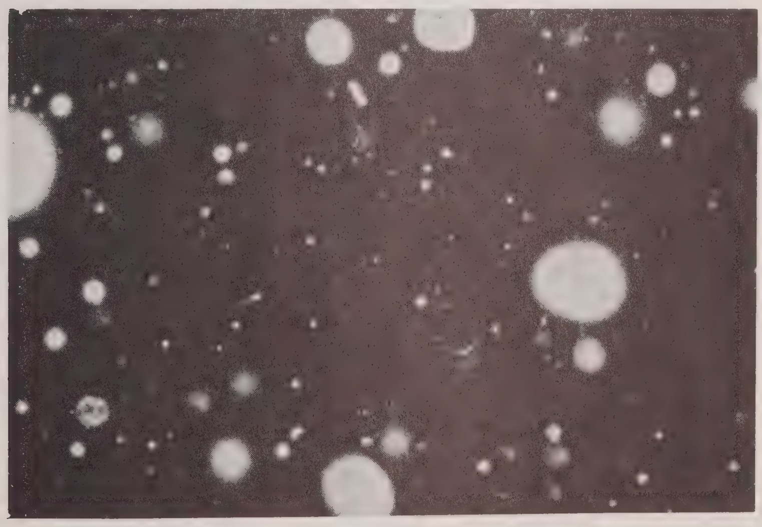


Fig. 4.3 Photomicrograph of sea water in oil emulsion, 40 x magnification. The largest particle on the left is approximately 300 microns in diameter.

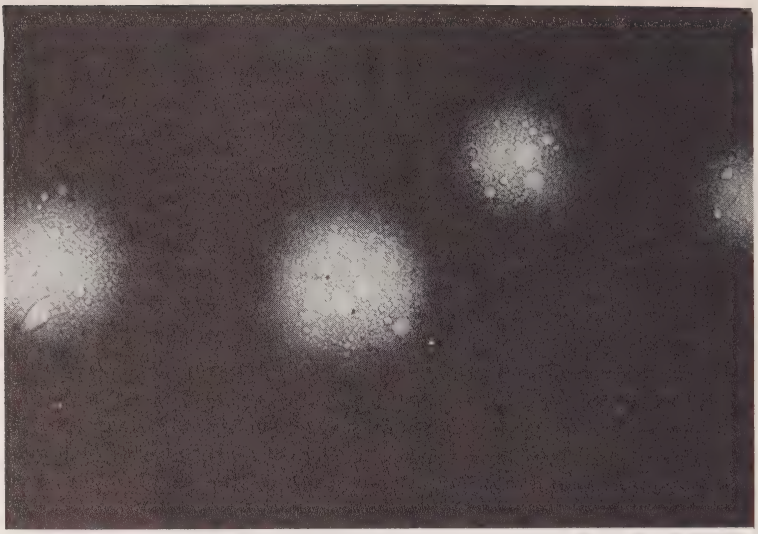


Fig. 4.4 Photomicrograph of sea water in oil emulsion, at 650 x magnification. The largest droplet is about 39 microns in diameter. The encrustation of small water droplets can be clearly seen.

4.2.8 The Stability of the Emulsion

Experiments to assess the stability of the emulsion were carried out at the Chemical Engineering Department of Nova Scotia Technical College. The viscosity of samples of emulsion maintained at various temperatures were measured over a period of time, assuming that the breakdown of the emulsion would be illustrated by a change in viscosity. Over a period of 120 hours, no significant decrease in viscosity was observed even with temperatures as high as 116°F. The water content fell slightly; a typical change being from 39% to 35%.

The stability of the emulsion can be attributed to the high viscosity of the continuous phase (the Bunker C), the slight difference in specific gravity between the two phases (0.05 compared with 0.15 for a typical Kuwait crude or 0.18 for marine diesel oil), and the small diameter of the water droplets contained in the emulsion. An additional factor must be the presence of an emulsifying agent. Prior research (Berridge et al, 1968; and Lawrence and Killner, 1948) has suggested that this emulsifying agent is connected with the asphaltene fraction and to test this theory, an emulsion of 40% water in de-asphalted oil was made up, the asphalt removed being 12% of the original oil. This emulsion was then maintained at 116°F for 80 hours during which time the viscosity was measured. The viscosity rose slightly and no significant change in the water concentration was noticed. This would suggest that the stabilization was not due to the asphaltene fraction of the oil, although Lawrence and Killner did suggest that an asphalt concentration of as low as 0.75% would be sufficient to stabilize an emulsion. The slight rise in viscosity was possibly caused by the oxidation of the resinous portion of the oil.

Viscosity measurements were also made on emulsion made with distilled water rather than sea water but no significant difference in behaviour was observed.

The conclusion drawn from this work was that a substantial breakdown in the stability and hence, viscosity, of the emulsion could not be expected from any increase in ambient temperatures in Chedabucto Bay. Breakdown would be possible in situations where the temperature of oil films exposed to sunlight rose substantially above the ambient temperature.

Fig. 4.5 Covering of grey skin forming on the surface of the oil, Bedford Institute, April 1970. The wrinkled area being pointed at has just been pulled back, demonstrating the texture of the skin.

4.2.9 Microscopic Examination of the Emulsion

Microscopic examination of the emulsion showed that the range of water droplet diameter was from below 1 micron to above 100 microns. A photomicrograph of the emulsion is shown in Figure 4.3 Examination of the boundary between the oil and the discrete water particles showed that each droplet was encrusted with hundreds of even tinier droplets. These can be seen in Figures 4.3 and 4.4, which is a photomicrograph at higher magnification. The encrustation must have considerable importance in the mechanism which causes the extreme stability of the emulsion.

Another interesting feature was that many of the droplets examined had considerable colonies of bacteria present, in spite of the fact that the emulsion was almost certainly formed at some time in February, and hence for four months these bacteria had existed, apparently quite successfully, isolated in a water droplet surrounded by oil. Some of the bacteria were estimated to be almost one-quarter of the diameter of the droplet in which they existed.

4.3 The Effect of Weathering on Bunker C

A program has been organized to study the changes in composition and properties of the Bunker C which has been deposited on the shoreline. This is a long term project and so far the available results are insufficient for comment. The processes likely to occur are evaporation, oxidation, and bacterial attack. It is expected that these changes will result in an increase in the asphaltene proportion of the Bunker C and hence an increase in viscosity. The proportion of saturated, open-chain material is likely to decrease.

As early as April it was noticed that the oil on the rocks had lost some of its "sheen" and that certain surfaces were covered with a grey film which was taken to consist of asphaltic material. A photograph of rocks covered in this material is shown in Figure 4.5, p.39. This film is much less tacky than the original oil and is much more impervious to penetration by materials such as limestone. Frequently, cracks in the film are observed, exposing mobile oil which can flow from the rocks thus causing recontamination of cleaned areas.

4.4 Detection of Origin of Pollution Samples

On several occasions it was necessary to ascertain whether a specific sample of oil had in fact come from the ARROW, a case in point being the oil washed up on Sable Island. The techniques used involved comparison of (1) physical properties, (2) vanadium-to-nickel concentrations ratio, (3) gas liquid chromatographs. Gas liquid chromatography was particularly revealing. Other methods examined were emission spectrosiopy, thin-layer chromatography, neutron activation analysis, and fluorescence spectroscopy.

Results of a typical analysis carried out at the Dockyard Laboratory of the Defence Research Establishment Atlantic (Stuart, personal communication, 1970) are shown in Table 4.4. Oil samples collected from Chedabucto Bay, Sable Island and from Clam Bay were examined and compared with a sample of oil recovered from the ARROW. It was concluded that the samples from Chedabuto Bay, Sable Island and the ARROW were of common origin whereas the sample from Clam Bay was not.

TABLE 4.4

ANALYTICAL COMPARISON OF POLLUTION SAMPLES

SAMPLE	"ARROW"	CHEDABUCTO BAY	SABLE ISLAND	CLAM BAY
Composition of sample, % vol.				
Oil	75	58	79	65
Water	25	39	17	15
Dry Solids	Trace	3	4	20
Properties of the recovered oil				
Sp. Gr. 60/60°F	0.96	0.96	0.96	0.99
Sulfur content % wt	1.9	2.4	1.9	2.6
Vanadium ppm	386	399	423	465
Nickel ppm	39	39	41	51
Copper ppm	10	2	2	2
Iron ppm	3	14	42	6
V/Ni ratio	9.9	10.2	10.3	9.1

5. ECOLOGICAL EFFECTS OF OIL

The heavy contamination of the shoreline of Chedabucto Bay has clearly had lethal effects upon wildlife, and particularly on the bird population. Oil is also present in the water column and on the sea bottom although the concentrations are very low. Available knowledge suggests that oil is not very toxic to marine organisms directly but there may be some very serious sublethal effects in the longer term. The ARROW incident provided an opportunity to study both the short term lethal effects and longer term sublethal effects of oil pollution. Catastrophic spills such as those caused by the wrecks of the ARROW and the TORREY CANYON amount to only a very small fraction of the total amount of oil spilled into the environment. It may well be that the smaller day-to-day spills have a far greater total effect upon the ecology.

5.1 Intertidal Subtidal Zone

Within a few days of the grounding, preliminary observations in the intertidal-subtidal zone were carried out (Thomas, 1970) on the south side of Janvrin Island where heavy oiling had occurred. At that time oil was adhering to periwinkles (*Littorina sp.*) and barnacles (*Balanus balanoides*), but the species were all alive. Such algae as *Fucus serratus* and *Ascophyllum* were partially oiled following drying during low tidal periods (Sharp, 1970). Observations of littoral algae were also made by Craigie and McLachlan (1970).

On February 26 a total of 42 dead fish (primarily *Ulvaria subbifurcata, Myoxocephalus scorpius, Liparis atlanticus* and *Pholis gunnellus*) were found near Janvrin Lagon, Janvrin Island causeway and Janvrin Harbour. Although these fish inhabit the near shore shallow water regions where heavy oiling occurred, they may not necessarily have died from the oil.

In early March an observational program was established (Thomas, 1970) with biological transects near Arichat Church, Janvrin causeway, Petit-de-Grat, Crichton Island and Little Barachois, and two stations in Janvrin Lagoon. From initial observations, horizontal zonations of typical flora and fauna were determined, as well as direct visual effects of oil contamination. Periodic sampling of the transects is continuing to reveal any changes of these effects and the rate at which oil clears from the organisms.

Common algae in order of decreasing height of occurrence above low water were *Fucus spiralis, Fucus vesiculosus, Ascophyllum nodosum and Fucus serratus.* Common fauna in the same order were *Littorina obtusata, Littorina littorea, Balanus balanoides* and *Gammarus oceanicus.*

In early May an assessment was made of the changes in the intertidal-subtidal zone over the period from early March to the end of April. No significant changes in algae took place, except that upper intertidal algae became completely covered with oil. Craigie and McLachlan (1970) have found no indication of direct toxic effects upon mature or juvenile plants. Few changes to fauna were apparent. The littoral amphipod crustacean, *Gammarus oceanicus*, either left or died in severely oiled locations. With the increasing temperatures *Littorina sp.* moved higher up the shore into severely oiled areas. Their shells were oiled, yet these snails remained active. Oily *Littorina Littorea* were observed (in rock pools) alive but unattached which is abnormal. Periwinkles appeared to be migrating from oiled to clean locations.

At the sampling stations in Janvrin Lagoon no significant changes were observed. However, oil was found in the sediment about the roots of eel grass, which is subtidal. Infaunal benthos was visibly oiled.

Observations were made of soft shell clams (*Mya arenaria*) in Janvrin Lagoon on

May 5 (Thomas, 1970). Excavation of clams revealed oil extending down most burrows and often forming a pool at the bottom. Clams generally moved up the burrow to evade the pools, and occasionally left the entire substrate. Some mortality occurred and even the live clams were unresponsive, although they recovered with prolonged exposure to air. Mortality (about 20%) appeared to be from suffocation rather than toxicity.

As a public safety measure, these non-commercial clam beds were closed. Further observations were carried out in May and June. By the end of June no further mortalities had taken place, although the clams still contained oil (Thomas, personal communication, 1970). The quantity and toxicity of oil in the clams will be determined before re-opening of the beds is considered.

In mid-February observations were also made (Sharp, 1970) on the sublittoral algae *Chondrus crispus* (Irish moss) which is of commercial interest. The highest concentrations were on Cape Auget, but these plants were either heavily epiphytized, or the location was almost inaccessible. Heavy oiling of the *Chondrus* was found on ledges off Janvrin Island and the Cape Auget shore. Fortunately, there are few commercial concentrations of *Chondrus* within Chedabucto Bay.

5.2 Sublittoral Studies

Although most of the Bunker C oil can be expected initially to be at the sea surface and in the intertidal zone, its relatively high density means that any small increase in density, or intense turbulence, can carry it below the surface. Early reconnaissance along the intertidal zone in Chedabucto Bay indicated that some of the oil which had come ashore and initially stuck to beach materials was coming free and carrying debris with it. In some instances it appeared that these patches of oil were about neutrally buoyant and even slightly negatively buoyant.

A benthic survey team was established in mid-February with representatives from the Fisheries Research Board units at St. Andrews and Dartmouth, and from the Resource Development Branch of the Department of Fisheries and Forestry, Halifax (Scarratt, 1970). The objective of this project was to carry out a visual assessment of the abundance and distribution of oil in the sublittoral zone, to make visual assessment of any damage that may have occurred to the biota and to sample the water, sediment and biota for chemical analysis of oil content. The extent and intensity of the survey in time and space would be dependent on the presence of oil on the bottom, the amounts which had entered the food chain, and the degree of persistence.

During the initial surveys February 26 to March 3, dives were made at 33 locations in the Isle Madame area and two near Canso, in depths varying between low-water mark and 70 feet and on all substrates from rock to mud. The initial surveys, chosen in areas where there had been heavy oiling along the intertidal zone, included 11 areas extending from Janvrin Island to Arrow Point on Petit-de-Grat Island. Oil particles were seen in the water, but no clear pattern of distribution could be distinguished. Particles and globules were most abundant in the surf zone. Oil was found on the bottom in only two of these areas. At Petit-de-Grat most of the oil found on the bottom seems to have been carried down on intertidal seaweed (Fucus serrata) to depths of 35-40 feet. At Jerseyman Island, in an unusual area of very calm water, oil on the bottom ranged from matchhead size globules to large pats of six inches diameter. All appeared to be weighted with sand or gravel and had one or more vertical protuberances (like inverted pear drops) which occasionally broke off and floated to the surface.

Subsequent surveys included revisiting some of the initial sites and investigating a few additional ones. An area off the Canso shore was surveyed where the shoreline was about 25% oiled (well-oiled patches with areas of clean beach and rock between). In deeper water the dominant marine invertebrates were the common sea

urchin and the starfish. No large attached algae or periwinkles were present. Some oil was found resting on, and floating just above, the bottom, 3-4 feet below mean low water.

Few lobsters were seen during the earlier surveys but became more in evidence as the water temperature rose. They appeared to be clean and normal in behaviour, although one was found with traces of oil on the ventral surface. Scallops were sampled close to heavily oiled beaches, cooked and eaten with no evidence of contamination. From visual examination there is no conclusive evidence of any significant damage to the sublittoral fauna or flora of Chedabucto Bay. A few fish were dead on the bottom in areas where dead fish had been picked off the beach, but there is as yet no evidence for attributing this to the oil. Examination of sculpins taken in the area where oil globules were present on the bottom revealed that oil was present in the faeces but not on the gills. Periwinkles contained oil in their faeces. Chemical analysis of a variety of animals (clams, scallops, periwinkles, sea urchins, etc.) revealed that oil is present not only in the digestive tract but in other organs as well as the muscle tissues (Zitko and Carson, 1970).

Having established that the fauna will ingest and retain oil in their systems, the field sampling is being continued in two selected areas; one of these is at Jerseyman Island, where oil was found on the bottom, and the second site is at Crichton Island where detailed studies of the natural clean-up processes are underway (see Section 3.4.4, p. 27). It is hoped that the persistence of oil in the biota, as well as some insight into any toxic and long range sublethal effects upon these biota, can be determined.

5.3 Plankton, Eggs and Larvae

The distribution of oil into the water column in Chedabucto Bay has been examined (see Section 3.2, p. 17), with the particles sizes (as low as 10 microns) well into the size range of the natural food of zooplankton. It seemed desirable, therefore, to investigate the ingestion of oil particles by zooplankton, the effect of this on the animals, and, conversely, the effect upon the oil particles of passage through the zooplankton animals.

In early March zooplankton samples were obtained (Conover, 1970) from the upper waters throughout Chedabucto Bay and visually examined for oil. The dominant copepod in plankton tows was *Temora longicornis*which had a dark bolus in the foregut during feeding. Faeces were also compact and dark, making visual confirmation of oil particles difficult. However, some pellets, and the foregut, contained a viscous, brownish, oil-like liquid or refractive index different from that of water, indicating that this was not a natural oil. A few *Calanus finmarchicus* had (in their intestines) brownish particles resembling Bunker C. Chemical analysis of faeces showed 2.4% Bunker C.

Animals containing smaller oil particles voided these within 24 hours and showed no signs of distress. On one occasion, a *Calanus* was observed with a very large particle blocking the foregut, which had fatal consequences. More generally, oil passed through largely unaltered, was defecated with other undigested food, remained in the form of fecal pellets considerably denser than sea water, and therefore sank. This may constitute an important natural clean-up process of oil in the sea. In addition, the fecal pellets contain a concentrated bacterial flora which should hasten degradation.

5.4 Fisheries and Fishing Industry

For the residents of the Chedabucto Bay area the sea represents, eigher directly or indirectly, a primary source of livelihood (see Dalziel, 1970). For many, either as fisherman or shoreworker, this industry constitutes the main source of income. Any major threat to the fishing industry is therefore of paramount concern.

The area directly affected by the ARROW disaster extends roughly from Dover in Guysborough County to St. Esprit in Richmond County. Within this area in 1968 approximately 1,000 fishermen were engaged, at one time or another in a variety of fisheries including groundfish, lobster, mackerel, herring, smelts, salmon, plus a variety of less important species. The total landings exceeded 78 million pounds for a total value of over $3 million. However, the bulk of these landings came from offshore fisheries. The landed value of the inshore fisheries is estimated at approximately only $500,000. Lobster constitutes the most important single fishery, and accounts for $338,000 (1965-69 average).

Fishing activity extends throughout the year, although a specific fishery may be only for a designated or limited period. From January to about August, herring are fished, while mackerel are fished from May to June and again from September to October. The lobster season is from April 10 to June 30 on the western side of Chedabucto Bay and from May 1 to June 30 on the eastern side. Groundfish are fished from April to November, and salmon from May to August.

In addition to the seagoing activities, there are four fish processing plants that employ close to 800 shore workers, of which approximately 750 are employed on a 12-month basis. Fish processing plants use copious quantities of water, and one plant is totally dependent on the sea as a source of water. Thus the threat of oil reaching process waters was ever present until a suitable filter system was installed (see Section 6.7).

One of the early questions in Operation Oil concerned the lobster fishery which, although closed at the time of the disaster, was due to be opened in April. In the field, scuba diving teams (Scarratt, 1970) found only limited amounts of oil on the lobster grounds. Lobsters living near heavily oiled shoulders did not suffer from impaired flavour. However, there was a danger of contamination by oiled fishing gear, smeared bait and oil slicks fouling floating storage crates.

Experiments were conducted by Wilder (1970) at the Fisheries Research Board's laboratory in St. Andrews, N.B., to simulate the possible contamination of lobsters in the various stages of the process from lobster trap to fish market. Numerous trials were carried out involving various combinations and concentrations of Bunker C and Corexit 7664 and 8666. The effects upon the flavour of the meat and tomale were evaluated by test panels of up to 24 persons. While some impairment of flavour did occur in certain cases, the concentrations of Bunker C used were very much higher than those found in Chedabucto Bay. It was concluded and later verified that the meat and tomale of lobsters in Chedabucto Bay would not become tainted by the oil, and that any oiling on the exterior of the lobsters could be cleaned by immersion of the lobsters in running sea water.

In summary, there has been no evidence to date that the oil spill has altered the yield of commerical fisheries in Chedabucto Bay. The major problems have been with contamination of the fishing gear, ships, docks and other equipment (see Section 8.4, p.81, see also Task Force Report).

5.5 Seals

In Chedabucto Bay there is normally a large population of grey harbour seals which although controlled is of no commercial value. Following the ARROW spill a weekly survey of seals was carried out (Mansfield, 1970) from March 2 to April 7, covering Inhabitants Bay, Janvrin Island, Isle Madame, Lennox Passage and eastward along the Cape Breton shoreline to Kempt Point. During this period only 500 grey harbour seals (13 dead) were seen where normally several thousand are found. Possibly, the oil pollution had kept them away, but the unusually heavy concentrations of aircraft, boats and personnel may have also contributed to their absence. A survey of seals on Sable Island was carried out (James, personal communication, 1970) from March 12 to 14. A group of 50-60 harbour seals and another group of

100 grey seals (11 dead) was observed. Most seals observed were lightly oiled and some heavily oiled, but only a small fraction of those observed (less than 5%) have been found dead. The oil has mainly affected the eyes, ears, nose, mouth and throat of the seals, often completely plugging some of these vital orifices and causing what occasionally appeared to be considerable pain and suffering. The cause of death was from suffocation rather than from any toxic effects of the oil.

5.6 Birdlife

A program to assess the effects of oil pollution upon the resident birds of Chedabucto Bay was carried out by the Canadian Wildlife Service (Watson, 1970). While the difficulties in collecting mortality data in the field were not inconsiderable, the main difficulty in the assessment stemmed from the fact that no reliable information of normal mortality rates was available.

Tuck (see Watson, 1970) describes the winter distribution of seabirds in Newfoundland as follows:-

Larus Gulls	Inshore zone, close to seashore
Alcids	Dominant in the offshore zone
Murres	Offshore and pelagic zones
Black Guillemot	Shallow littoral zone
Puffins	Offshore and pelagic zones

With no others available, Watson (1970) has taken these populations as being applicable as normal distributions for Chedabucto Bay. His observations during February and March did not contradict this assumption. In addition, several other common winter residents of the inshore waters of the Bay were observed. Oldsquaw were seen in the inshore zone on a variety of coastlines, while red-necked and horned grebes are rare residents of the coastal zone. Red-breasted Mergansers are permanent residents and in winter prefer open streams and tidal rips in the coastal zone. The Golden eye is a common winter resident favouring shallow bays and river estuaries. Bald eagles, residents of Cape Breton Island, were also observed in the coastal region.

Watson made field observations on February 9, and 13 to 16, and has summarized his results according to the degree of contamination of the shoreline. Areas with the heaviest contamination also had the largest number of dead birds, which presumably washed ashore with the oil slick (Watson, 1970). The scarcity of oiled living birds in heavily oiled areas indicates that the birds may be immobilized in the heavy oil and die soon after. In light concentrations of oil many birds were not immobilized and were thus able to survive. The estimate of dead birds washed ashore was 1150 for heavily contaminated shores, and 400 for moderately contaminated shores. Allowing for 10% underestimate in sampling and a mortality of 300 birds on non-oiled shores (which were not extensively studied), Watson estimated that the total kill on or about February 16 was about 2,000 birds. After this date no further large amounts of oil were released from the wreck and consequently no further dramatic effects on birdlife were observed.

It should be cautioned that Watson's estimate of 2,000 birds is the number of dead birds washed ashore, some of which may have died from natural causes. However, it has been pointed out, for example by Tanis and Bruyns (1968), that the total death rate at sea is estimated at anywhere from 6 to 25 times more than the number washed ahsore. Thus, although Chedabucto Bay is not the open sea, the death rate may still be considerably greater than 2,000. In addition, no estimate has been made of the long term effects upon the bird population in Chedabucto Bay.

Fig. 2.1 Geographical locations in Chedabucto Bay, Nova Scotia.


St Peters
ST. PETERS BAY
L Ardoise
PASSAGE
St. Peters I
Cap Ronde
Red Pt
10
Michaud Pt
Isle Madame
20
BAY OF ROCKS
Shaw Pt
rt Royal Hbr
st Arichat
Arichat
Petit-de-Grat I.
30
man I.
ape Auget
Orpheus Rk.
50
Forest Cove
Green I.
Arrow Pt
Heath Hd
Red Hd
PETIT-DE-GRAT INLET
30
20
50
ATLANTIC OCEAN
TO BAY
50
50
50
French Pt
Durell I.
Grime Rk.
30
20
Canso
Tickle Chan.
George I
Cranberry I.
CANSO LEDGES
20
Glasgow Hd.
GLASGOW HBR.
Cape Canso
Andrew I
OVER HBR.
duck Cove
DOVER BAY

Following reports that oil (reportedly from Chedabucto Bay) had reached Sable Island, Locke (personal communication, 1970) carried out a two-day survey of the Island from March 11 to 13, 1970. During this survey, a number of dead birds was observed. Brown (1970) carried out a later survey from May 15 to 25, 1970. From sampling along the shoreline, Locke estimated that close to 5,000 birds had died and were washed ashore on Sable Island. It has not been possible to determine the proportion of these birds that became oiled and died before being washed ashore, or the proportion that were oiled after drifting ashore.

5.7 Sheep

Along certain sections of the Cape Breton shoreline near Sterling and St. Esprit, sheep have access to the shore where they eat seaweed. On April 1, four sheep were alleged by the owner to have died from eating oiled seaweed. It was therefore necessary to determine the cause of death of these sheep and to study more generally the effects of Bunker C ingestion.

Autopsies indicated that all four sheep had died from worm parasitism and not from ingestion of oil. Nevertheless, since ingestion of oiled seaweed was potentially a hazard to the sheep, feeding experiments were carried out by the Department of Agriculture (McIntyre, 1970). No ill effects upon the sheep were detected. However, since external oiling may reduce the natural insulating quality of the fleece, and also its commercial value, sheep pastures were fenced off from oiled shoreline as a preventive measure.

6. CONTROL OF RELEASED OIL

When oil has been released into the sea, there are many ways to try to control it and defend vital areas. No system has proven reliable over a wide range of environmental conditions. Indeed, there are a surprising number of products and techniques which do not even function satisfactorily in the specific conditions for which they were supposedly designed.

Some ways of controlling oil slicks lead to removal of the oil from the sea, others do not. Removal techniques such as booming and pumping, absorbing, burning or skimming are greatly to be preferred, because removal reduces or eliminates the threat to the ecology and the shoreline. After removal, however, the provlem of disposal of any collected oil remains.

Methods such as sinking and dispersing do not remove oil from the marine environment but only remove it from the water surface. Not only is the oil merely redistributed into the water column or onto the sea bottom, but many of the methods of redistribution depend upon the addition of chemicals and other material to the water. Contamination of the marine environment by both oil and chemicals may be very harmful to the ecology although the exact effects are yet unknown. Techniques which remove the oil are certain to be preferred over those which do not, but circumstances may not always permit the luxury of a choice of action.

6.1 Absorbents

6.1.1 Peat Moss

(1) Field Trials

Coupal (1970) cooperated with the Atlantic Regional Laboratory, National Research Council of Canada, in February, 1970, to conduct both field trials and laboratory experiments on the use of peat moss as an absorbent for Bunker C oil at low temperatures. Preliminary laboratory research had shown that peat moss absorbs oil in preference to water. The field trials were done in the Chedabucto Bay area during February and early March.

In tests on February 18, peat moss was applied to a slick of 20 square feet and the mixture dragged ashore easily by use of a vertical ¼ inch wire mesh screen. On February 25 three patches of 5 square feet were treated individually on shore with sawdust, straw, and peat moss. Sawdust did not stick to the oil while straw stuck to the surface but the mixture was difficult to collect. Peat moss stuck well and this mixture was easily collected. The gathering of oil slicks on the open sea was tried by applying peat moss to the slick and then dragging the mixture with a boom (see Section 6.2.2, P. 53) made of ¼ inch mesh screen 20 feet long and 5 feet deep. Moderate success was achieved.

These field trials confirmed laboratory evidence that peat moss could be effective for collecting oil slicks on the sea and that cleaning of oiled beaches appeared feasible using peat moss as an absorbent aid. The raking of the mixture provides mechanical energy which increases absorption, yet the mixture does not stick to the rake. However, while shore cleaning with peat moss was successful in February, the technique failed in March —— presumably due to the combined effects of "weathering" and increased formation of sea water-in-Bunker C emulsion (see Section 4.2.5, p. 36). Obviously, of course, such a beach cleaning technique is never well suited to boulder or rocky shorelines.

Peat moss was used extensively in cleaning beaches near Glace Bay, Nova Scotia, contaminated with Bunker C oil in April after the sinking of the ferry "PATRICK MORRIS" in the Cabot Strait.

Although further investigation is needed, peat moss is a very effective absorbent for Bunker C oil released into the sea provided it is used within the first week or two of the release having occurred. Field trials showed it to be more effective at low temperatures (28 – 30° F) than other low-cost absorbents. Other advantages are that peat moss is available in large quantities from sources often close to where oil is most likely to be released into Canadian waters, that it can be stockpiled without its efficiency deteriorating, and that its effectiveness is not greatly affected if it is used wet or even having been wet, is used frozen.

With the early success of peat moss as an absorbent, a device was required which would spread peat moss quickly and evenly on an oil surface. A small horn-type snowblower was modified by blocking off the snow inlet and adding a hopper for feeding the peat moss. Trials (Gibson, 1970) demonstrated that 6 cubic feet of peat moss could be spread in two minutes. Following this success the Task Force requested that another unit be built, and kept both units on hand for use as required.

(2) Laboratory Trials

Following the field trials in Chedabucto Bay, Coupal (1970) conducted further laboratory trials to assess the absorbency of peat moss. Emulsions varying in water content were used. In addition, several other absorbents were briefly assessed and compared with peat moss (see Section 4.2.5, p. 36).

Although laboratory results indicated the efficiency of peat moss as an absorbent for Bunker C oil would be greatest for emulsions containing 40% water, this was not verified in the Chedabucto Bay area field trials. In laboratory tests the mixtures were vigorously stirred at 70° F so that the viscosity would have been lower and other parameters affected. Certainly the intricacies of the effects of temperature, water emulsification, "weathering" and other parameters on the mechanism of oil absorption by peat moss are not understood and require further investigation as does the possibly increased practical efficiency of using "long-fibre" or unshreaded peat moss rather than the horticultural product available to "Operation Oil".

6.1.2 **Polyurethan Foam**

Polyurethane foam is oleophilic and absorbent. Sea water-Bunker C emulsion at low temperatures, because of its high viscosity, penetrates absorbent materials with great difficulty. Polyurethane foam formed *in situ*, however, is preheated and ejected from a nozzle at 120° F. The reaction that follows is exothermic and the foam provides excellent insulation. Emulsion beneath the foam formed *in situ* is thus heated and better absorption is promoted.

Experiments (Whiteway, 1970) were conducted in Guildfords Limited, Dartmouth, N.S., with observers from OPeration Oil. Oil on wood, cardboard, sand or water received a coating of foam ½ to ¾ inch thick. On solid substrates, some emulsion extruded through the foam within minutes and some was left clinging to the wood base when the foam was pulled off. In several cases cavities appeared between the foam and the emulsion, possibly caused by steam. On water, foaming action was slower because of heat losses to the water. After oil was entrained in the foam by stirring, the mixture hardened into a clean and easily handled matrix which floated. The high cost of polyurethane foam probably restricts its application to special situations. Moderately effective as an absorbent, then hardened foam can also be left in place to improve the appearance of complex oiled solid surfaces which cannot be cleaned acceptably.

6.1.3 Urea-Formaldehyde Foam

In early May, urea-formaldehyde foam was suggested as an oil absorbent. Test trials (see Foote, 1970) were done in the Crichton Island causeway area. However, 30 minutes after application, not only had no visible absorption taken place, but the hardened foam could not be removed from the oiled shore.

6.2 Containment

Containment devices of various kinds were used extensively in Operation Oil, and a number of innovations were assessed. In general, these trials were dealt with directly by the Task Force and are summarized in their report. The scientific team undertook literature surveys and gave advice on boom designs and on the hydro-dyanmic behaviour of oil against booms. The scientific team also designed and evaluated (laboratory and field) a wire mesh peat moss boom and a seine net boom.

6.2.1 Conifer Boom

One innovation to emerge from the operations in Chedabucto Bay was the conifer boom: a vertical weir of wire mesh covered with spruce boughs. The Task Force reported that this porous, oleophilic boom would contain Bunker C slicks in currents ranging up to 6 knots and that such booms effectively prevented the entry of oil into a number of unpolluted embayments whose entrances were as wide as 1,000 feet (e.g. Guysborough Inlet).

In contrast, it is generally recognized that commercially available semi-flexible, non-porous booms in common use fail in currents greater than about 1.2 ft/sec (about 0.7 knots), depending on oil quantities and channel widths. Laboratory experiments have shown (Wicks, 1970) that while draining of oil does occur adjacent to a non-porous boom, the primary cause of boom failure in a current is the tearing off of oil droplets from the gravity wave that forms at the upstream end of the oil slick. In heavy sea states, however, failure is also caused by the breaking of waves over the top of the boom. Wicks (1970) has also shown air bubbler barriers to fail in currents as low as 0.7 ft/sec (0.4 knots).

6.2.2 Wire Mesh Peat Moss Boom

Since peat moss had proven an effective absorbent for Bunker C floating on water (see Section 6.1.1, p. 51), a simple way to corral the peat moss-oil mixture was needed. A prototype wire mesh boom was designed and constructed (Coupal, 1970; Sellars, 1970). The main body was ¼ inch mesh galvanized screening, 3 feet high, with floatation by styrofoam floats at mid-height. Pieces of 2 x 2 inch wooden stiffeners were attached at 5 foot intervals and a towing bridle attached at each end. This arrangement was successfully used in trials to collect peat moss that had been applied to an oil slick. It was also shown that this device can be used to contain oil slicks on the sea surface if peat moss is spread along the length of the boom on the upstream side.

6.2.3 Seine Net Boom

It was necessary to corral a number of small oil slicks floating about in the Bay using locally available small fishing boats. If a fish net could hold the oil, it would be an attractive solution, and also offer promise for containment of larger scale slicks and slicks in rough water, particularly those caused by the accidental further release of oil from the wreck (see Chapter 7). Nets,inherently flexible, should, if they would retain oil, be more effective than conventional semi-rigid or rigid booms in anything but almost calm conditions. Permeability of the net might also permit the passage of water while retaining the oil, thus making the net boom attractive in strong current situations or for towing a boom of oil into a protected area where removal techniques could be more easily applied.

Laboratory trials were carried out by Brooke and Dobson (1970) at the Atlantic Oceanographic Laboratory. An outboard motor maintained a circular current in a 28 inch deep, 8 foot diameter tank. Test nets were hung across a diameter of the tank. When Bunker C at 0° C was released from the bottom of the tank into a light current, less than 5% of the oil escaped through the net in a 15-minute test. As the current was increased and wave action created, the escape of oil did not increase, but rather, the oil sank at the net and adhered to the net in a vertical layer. A range of parameters, including mesh size, was studied. Use of a ¾ inch mesh nylon twine seine net seemed optimal for containing Bunker C.

The design and construction of a seine net for a full scale containment trial was carried out by Johnston (1970) of the Department of Fisheries and Forestry. Important considerations were to use readily available material and design the seine so that it could be used by "Cape Islander" lobster boats.

A net was constructed to depth 5 fathoms and length 180 fathoms (in three sections of 60 fathoms each). The middle section, or bunt, was made up of 210/21 x ¾ inch mesh nylon twine. A three-foot strip of 210/12 x ¾ inch mesh was attached to the head rope, wrapped up over the floats and fastened to the main net, thus giving double netting two feet below the water surface.

A trial was carried out in oil-free water northeast of Green Island. Two 40-foot boats were employed, each with a crew of four. Only 15 minutes were required to set the net and another 15 minutes to tow the net in V-formation. In the retrieval of the net each boat collected one-half of the total, and then it was completely landed onto one boat. This operation took only 30 minutes.

Following further testing and slight modification to the net, a demonstration was given for Captain Martin of the Task Force and some other officials. It was generally felt that the net would successfully contain Bunker C oil in cold water although it was never tested on a slick. Arrangements were made with one of the boat owners to care for the net and to coordinate its deployment in case of an emergency.

6.2.4 Current Measurements

A number of current surveys (Neu, 1970) were carried out in March to provide information to the Task Force in their assessment of the feasibility of boom installations at a number of locations. Further measurements were made in conjunction with the construction of a causeway in Lennox Passage.

In early March, heavy pollution in Inhabitants Bay threatened the Inhabitants River system, and the installation of a log boom was considered. Accordingly, current measurements were carried out in the river in March, following which it was concluded that such an installation was feasible. In Guysborough Inlet, currents were measured for 14 hours on March 18 just inside the Inlet, and for 9 ½ days commencing on March 18, at the mouth of the Inlet, following which the Task Force installed a brush boom. Current measurements were also carried out over a complete tidal cycle in Petit-de-Grat Inlet on March 25.

In Lennox Passage a dam (a form of protective containment) was constructed at the highway bridge to prevent the heavy concentration of oil on the shore and under the ice in the western part of the Passage and in the Inhabitants Bay area from moving into the region east of the bridge. When the ice plug broke up, this causeway served to protect the St. Peters Bay area from contamination.

Current measurements made during the gradual closure of the Passage (March 11-17) shoed corresponding increases in current velocity. Tidal measurements after closure revealed some interesting seiches with periods of about two-hours, which were also detected in tidal records from Port Hawkesbury. Although it has been ascertained that these seiches are restricted to the northern side of the Bay, the exact

system of oscillation has not yet been determined. An understanding of these hydraulic characteristics is a prerequisite to the assessment of the ecological effects of the presence of the causeway. The Passage will be partially opened at a later date, possibly to the width of the swing span of the bridge and to the full depth of the channel. Current predictions for such an opening are presently being calculated (Neu, 1970).

6.3 Oil Removal from Fish Plant Water Supplies

Oil contamination in Chedabucto Bay posed a serious threat to fish-packing plants at Mulgrave, Canso and Petit-de-Grat because these plants use substantial quantities of salt water in their process. Concern for the Mulgrave and Canso plants was reduced when arrangements were made for alternate fresh water supplies should an emergency arise. However, the threat to the Petit-de-Grat plant required some other solution, since local fresh water supplies were at first judged quite inadequate to service the plant even on a reduced basis. Alternate fresh water supplies for the Petit-de-Grat plant were later made more adequate when the Task Force, with the cooperation of Provincial authorities, arranged for another well to be drilled and connected to this plant.

6.3.1 Laboratory Testing

A laboratory study on the removal of emulsified Bunker C oil from sea water was undertaken by Sparks *et al* (1970) at the Chemistry Division, National Research Council of Canada. Three approaches were adopted: (1) filtration, (2) collection by agglomeration, and (3) chemical treatment to increase the particle size of the emulsified droplets.

Materials tested as filter media included petroleum coke; coked coal, coarse nylon powder, polystyrene powder, styrofoam, polypropylene fibre, polyurethane foam, filter paper, boiled sawdust and oil shale. With suitable packing in the filter bed, most of these materials (except sawdust and filter paper) removed oil satisfactorily. The main difference amongst these materials was capacity. Coked coal appeared to be the most acceptable, and Sparks carried out more detailed work on this media. However, one possible side effect of coked coal is that it imparts a slight turbid suspension to the water.

In a parallel filtration study at Defence Research Establishment Atlantic – Dockyard Laboratory, Tambon (1970) conducted a number of tests using wool felt. While this material, when fresh, effectively removed oil, it was found to plug quickly, reducing flow by 70% in 24 hours (Gibson, 1970). Backwashing did not improve performance sufficiently to make wool felt a satisfactory high capacity filter media.

Another approach was to agitate the emulsion in the presence of finely divided hydrophobic solid particles. The agglomerated solid would then float or sink. Solids tested included Darco activated carbon, McBean Coal, and partially dried ground peat moss. These worked well but the water was not as clear as after filtration. Sparks suggested that this technique might be useful as a pretreatment step before filtration.

Emulsions can be separated if the rate of coalescence of the emulsified droplets is increased, leading to an increase in average particle size. Almost any electrolyte will have this effect. Sodium chloride and calcium chloride were tested. Although such treatment might serve as an aid to filtration, its use alone was not judged practical for dealing with large flows of water since separation rates were slow.

6.3.2 Polyurethane Foam Packed Absorption Tower

(1) Pilot Plant Studies

In association with Canadian Plant and Processing Engineering Limited who had been authorized by the Task Force to construct a filtration system for the Petit-de-Grat fish packing plant, a pilot plant model was constructed at the Atlantic Oceanographic Laboratory for the study of the removal of Bunker C from sea water. Staff from the Atlantic Regional Laboratory, National Research Council of Canada provided analytical chemistry support. Principal criteria were that the system have a capacity of 600 gal/min, capability for gravity feeding, simplicity of design, and allowance for both continuous and batch operations. Three forms of polyurethane were investigated:

(i) rigid polyurethane chips, 1 inch diameter;

(ii) flexible polyurethane chips, 3 inch cubes; and

(iii) flexible polyurethane discs, 20 inches diameter, 4 inches thick

Testing of various configurations showed that a combination of 3-4 foot of rigid polyurethane chips with 4-8 inches of continuous flexible polyurethane on the bottom seemed the most effective combination. This permitted gravity feeding at 600 gal/min through a 20 inch diameter absorption bed and was nearly 100% effective in the removal of Bunker C, except when dispersant Corexit 8666 was present in the feed water, in which case removal was 97%.

(2) Petit-de-Grat Installation

Canadian Plant and Processing Engineering Limited (1970), on the basis of preliiminary laboratory experiments with polyurethane as a filter media, were authorized by the Task Force on March 6 to design and construct filtration systems for the fish plants at Petit-de-Grat and Canso. Work for the Canso plant ceased on March 8 when an alternate fresh water supply was found acceptable. Design of the 600 gal/min capacity plant for Petit-de-Grat commenced March 7 and was readied for operation on site by March 25. Specifications for this absorption tower are similar to those resulting from the above described pilot plant study.

6.4 Mechanical Removal from Water

6.4.1 Pumping or Conveying

In late February and much of March, a large part of the perimeter of Chedabucto Bay was covered with ice, and large pools of oil were found adjacent to the ice sheets (see Section 3.3 P. 18). It was suspected that significant pools of oil were also trapped in pockets underneath the ice, although attempts to measure their volume were not successful. The option of pumping was investigated as a method of recovering this oil before it escaped when the ice melted and caused further contamination of the shoreline.

On March 10, with the help of Emergency Measures Organization personnel, a test through the ice was conducted near the southeastern end of Janvrin Island. A 4 in. diameter diaphragm pump — the type used for pumping out septic tanks — was used, but the viscosity of the Bunker C proved too great and almost immediately the pump came to a complete halt.

Dessureault (1970) conducted a survey for a pump which could handle the emulsion. Five pumps were found which were stated to be suited to handle fluids with viscosities about 100,000 Seconds Saybolt Universal units (roughly 208 poises). The pumps were 1) "Moyno", 2) "Sier-Bath", 3) "Roto-King", 4) "Wavkesha", and 5) "Blackmer". From a survey of published data Dessureault recommended that for very viscous oil and for oil contaminated with solid material and salt water, the Moyno and Sier-Bath seemed the most suitable. For lower viscosities but higher

capacities, the "Roto-King" and "Wavkesha" should be considered. For pumping of such highly viscous materials as cold Bunker C, it is critical to have a very short intake pipe, which in turn requires that the pump must be fed by some collection device. No field tests were undertaken because most of the shore-fast ice in the Bay was gone before any of the pumps could be delivered and prepared for testing on the ice.

Since pumps with long intake pipes proved ineffective in removing thick pockets of oil trapped under ice, an alternative method was investigated. Tests of the Chemistry Division, National Research Council of Canada, (Puddington, personal communication 1970) indicated that a screw pump or conveyor might pick up this thick oil. This removal system might also combine well with the collection of oil by seine nets (see Section 6.2.3 P. 53).

After discussion with the Task Force, Gibson (1970) arranged with Sullivan Mill Equipment Limited, Toronto to construct a screw conveyor, 10 ft. in length and 12 in. in diameter, driven by an internal combustion engine. By the time it was delivered to Chedabucto Bay on March 25, no deep oil pockets which it had been designed to handle, could be found. A test which proved unsuccessful was carried out on a shallow oil slick containing seaweed, and the project was abandoned.

6.4.2 Skimming

The "Oleovator", more commonly called the "Slick-licker", has been used extensively, almost exclusively, in Chedabucto Bay for the removal of oil and oil mixed with seaweed (and other debris) from the surface of the water (Sewell, 1970). This may serve to indicate its superiority over other equipment tried. While its use was handled directly by the Task Force, Scientific Coordination has followed the Slick-licker with great interest.

The Slick-licker is basically an oleophilic, continuous, belt-type skimmer, mounted on a frame and extended obliquely well down into the water. As the belt revolves, oil is preferentially picked up while water is left behind. The important feature is that as long as some part of the length of the belt remains in contact with the oil surface, oil will be picked up. In contrast, suction devices require that the orifice maintain a level with the sea surface at all times if efficiency is to be achieved. Thus, weirs and suction devices are efficient only in the calmest sea conditions. The Slick-licker by its very lengthy extension into the water, has a built-in partial response to waves, requiring a much slower response to maintain contact with the oil. This simple concept is practical.

Although it is available on a commercial lease or sale basis (as to Operation Oil), the Slick-licker is nevertheless undergoing continuing development. Prior to its use in Chedabucto Bay it had been used successfully on lighter fuels but had never been tried on Bunker C. At the request of the Task Force, tests were undertaken in Colwood B.C. on Bunker C fuel by the inventor, R.B.H. Sewell, of the Defence Research Establishment Pacific. On March 13 and 15 field trials were conducted in Chedabucto Bay. Following these tests modifications were made to facilitate off-loading of oil directly into barrels and to strengthen the machine components because of the stresses expected when dealing with Bunker C-sea water emulsion and oiled seaweed. Three additional machines incorporating these modifications were constructed at the Port Hawkesbury Shipyards Ltd. and readied for action by April 8, 12 and 18 respectively.

During oil recovery operations, three machines were mounted on 27—ft. self-propelled barges and one on a catamaran (see Task Force Report). Actual recoveries at rates up to 45 gallons/minute demonstrated the effectiveness of the oleophilic belt. In places such as Inhabitants Bay large amounts of oiled seaweed were successfully removed but this application required manual assistance. The barges were suited for this activity.

The Slick-licker has shown itself to be effective when significant quantities of oil could be found. Although it was by far the most efficient device for mechanical oil removal tried in Operation Oil, further research and development is still required. Such a device should be coordinated with a containment system so that a continuous source of oil is provided and maximum efficiency of the machine is maintained. Conversely the use of a Slick-licker can supplement a containment system, for example, by drawing off oil and relieving the hydraulic pressure of an oil slick against a boom. The further development of the Slick-licker and its coordination with a containment system will be a large step towards an all-purpose, all-weather oil removal system.

During the course of Operation Oil, a number of suggestions on skimmers, weirs, and other surface collectors were received. Most of these were not considered to be directly applicable to the ARROW clean-up, especially since the fleet of Slick-lickers appeared to be performing satisfactorily.

One proposal for a skimmer was investigated further by Brooke and Dessureault (1970). The original concept, proposed by Mr. James Magill of Truro, N.S., was based on a rotating disc which extended flatly but obliquely into the water from an axle on a barge. As the disc rotated oil would be picked up by the disc on its upper surface and a scraper would spill the oil into the barge. However, this concept suffers, as many skimmers do, from an inability to cope with any significant wave activity.

A modified version was built and tested in which several discs are mounted vertically on a horizontal axle, arranged to permit a greater extension of the disc into the water and collection on both sides of the disc. A plywood model was constructed and tests were carried out with Bunker C and a lighter (SAE 30) oil. These experiments were recorded on films, Nos. 1600 and 1601, available from the Atlantic Oceanographic Laboratory. Although tests were limited in scope, they indicated this method may be effective in sea states that are prohibitive to other techniques.

6.5 **Burning**

Most burning trials in Chedabucto Bay took place prior to the formation of the Task Force, and centered around the use of "Seabeads", a product of Pittsburgh Corning Corporation. "Seabeads" are ¼ in. diameter cellulated glass beads which float on the sea surface and produce a wicking action on the oil. Once the slick is ignited, the "Seabeads" help provide insulation against the heat sink of the water below. Trials were conducted by Pittsburgh Corning chemists and LeFeuvre (1970) in the period February 9 – 15. The Fisheries patrol vessel SHEDIAC BAY assisted in the tests at sea.

A preliminary test was carried out on a beach near Arichat on February 9. A ½ in. coating of fresh Bunker C was easily ignited and cleanly burned using "Seabeads". On February 10 several small slicks from 2 to 6 ft. in diameter were located near the wreck, and "Seabeads" were applied. Ignition was achieved by adding "Varsol" and lighting a flare. In the 2 to 3 ft. seas, burning of the slicks was moderately successful with only a small amount of residue remaining. Testing in open water was discontinued because no further slicks could be located. The next day Imperial Oil constructed a boom from oil drums to contain oil during combustion. A lighter grade of Bunker C was used in testing the boom and, surprisingly, combustion was maintained without the use of "Seabeads" but the downwind oil drums ruptured from the intense heat.

Following the sinking of the stern section of the ARROW on February 12, the emphasis on burning shifted to shoreline clean-up. Very little success was achieved in burning oil collected in tidal pools probably because much emulsification of the Bunker C had already taken place. U.S. Army personnel arrived on site and

attempted ignition with "flame throwers" but combustion could not be maintained. By February 15, large scale burning experiments in Chedabucto Bay had been discontinued.

Burning trials at sea by the U.S. Navy in May, 1970, have been reported by Payne (1970). These trials were conducted from the USS COMPTON at position latitude 42° N, longitude 64° W, which is 135 miles southeast of Yarmouth, N.S. Two products were investigated; "Seabeads" from Pittsburgh Corning Corporation and "Cabosil", a hydrophobic silica powder from Cabot Corporation. Neither product was successful by itself in promoting burning of Bunker C on the open Sea. Although "Cabosil" was somewhat more effective than "Seabeads", in both cases large quantities of kerosene and gasoline had to be added for ignition and, in both cases, burning soon stopped.

A quantity of material called "Kontax" was obtained by the Task Force through the Canadian agent, Canadian Mannex Corporation Ltd., Montreal. "Kontax", manufactured by Eduard Michels GmbH, Essen, Germany, is a paste containing calcium carbide and metallic sodium as the active ingredients. The material ignites on contact with water, producing a hot flame which is claimed to be capable of igniting oil floating on water. In practice, a number of packages are dropped at the windward edge of an oil slick. The wind, fanning the flames over the slick, produces a fire-storm effect. Ten tons of freshly spilled Arabian crude oil were ignited in this way in a demonstration in the North Sea.

In the one successful experiment at Chedabucto Bay (Sheffer, personal communication, 1970), two drums of Bunker C freshly spilled on the surface of a small cove were completely burned using the above technique. In this case, because the wind and waves prevented the slick from spreading, the thickness of the oil varied from ½ to 2 in. Other attempts to ignite weathered oil slicks in the Bay met with failure, indicating that the water-in-oil emulsions will not support combustion.

"Kontax" is believed to hold promise for the ignition of freshly spilled oil, but the method of application of the material leaves much to be desired. In the case of light oils it is possible to drop the packages through the oil with the reaction taking place at the oil-water interface. Since this procedure is not possible with thick slicks of Bunker C fuel, the only feasible melthod is to locate the packages very precisely at the windward edge of such slicks. A mechanical method for precise application is required if the material is to be of practical value.

These experiences show the need for further research and development on methods of burning oil slicks. In cases of oil spills in isolated areas or amidst ice, burning may be one of the few methods of control. In the laboratory, some experiments have already been carried out to study the effects of emulsification on the ignition temperature of Bunker C (see Section 4.2.4 P. 34). Presently a search is being made for a feasible burning technique to dispose of oil and oiled debris collected during beach cleaning operations. Methods based on a counter-current design, where the material to be burned is scrubbed by flue gases before reaching the combustion zone, show promise, and modification of a commercial asphalt-aggregate drying plant may be practical.

6.6 Sinking

The sinking of oil as a control measure was not adopted in Operation Oil because other, more satisfactory, methods were available. Nevertheless, the option to use this technique was maintained; the literature was surveyed extensively and the advice of experts obtained.

The technique has a number of disadvantages. The deposition of oil (and sinking agent) on the seabed would probably be harmful to the biota. Trawl fishing would also be affected adversely since fouling of fishing equipment would be unavoidable. Furthermore, there is no assurance that sunken oil will remain on the seabed.

A promising approach to sinker technology has reportedly been tried extensively by Royal Dutch Shell in European waters and by the U.S. Army in North American waters. A modified suction dredge is employed in collecting and treating the sand with amine acetates to make it olephilic and then applying it as a 10% slurry in sea water through outrigger booms at a rate of one part sand to one part oil. On fresh crude about 50% of the oil can reportedly be sunk, while up to 90% can be sunk in the case of residual oils or crudes which have aged and lost most of their volatiles.

6.7 Dispersants

Probably the most widely used technique for control of small to medium size oil spills has been the use of chemical dispersants; in the case of the TORREY CANYON and the WORLD GLORY they were used on a very large scale. Much development work has gone into formulating more effective and less toxic products, and there are numerous brands on the market. The decision to use a dispersant should be made on the basis that the accruing benefits outweigh any bad effects on the biota. This has rarely, if ever, been established with any degree of certainty since the ecological effects of oil/dispersant in water are still largely unknown. Use of dispersants where there is rapid dilution has been condoned by others, mainly on the assumption that with such dilutions no serious effects were to be expected because there was no definite evidence of gross harm.

Dispersants were not used operationally by the Task Force, but this option was reviewed continually. Of major importance was the fact that it was not possible to assess the ecological effects if a dispersant were to be used on an operational scale. However, since dispersants remained an option, a number of the commercially available products were assessed. Results of toxicity tests are summarized later in this section.

Until April 11 when debunkering of oil from the stern section of the ARROW was completed, there was always a threat of a new spill should the wreck break up. The option of using dispersants was maintained as part of contingency planning. The use of dispersants within Chedabucto Bay was virtually ruled out because of the risk of affecting marine flora and fauna and the risk of increasing the threat of contamination of sea water supplies to fish plants in the area (see Section 6.3.2 P. 56). Much of the shoreline was already oiled and further oiling did not seem sufficiently serious to warrant the use of potentially toxic materials.

Should a significant oil slick move out to sea, the application of a chemical dispersant seemed the only option offering much hope of success in preventing the slick from being blown back towards the shore and threatening uncontaminated shoreline along the Nova Scotia coast. It is highly likely that the sea state would not permit satisfactory containment of such a slick and, combined with a high degree of emulsification and loss of volatiles, the slick would be almost impossible to burn. Under the vigorous mixing conditions pertaining in winter the opinion of the scientific team was that, on balance, the danger to the biota would be minimized if the slick were dispersed at sea.

Despite the many unanswered questions regarding the biological effects of the use of dispersants, it was shown during the TORREY CANYON incident that dispersants such as BP 1002 can be effective for cleaning oiled shoreline. With only moderate success being achieved in the cleaning of beaches bordering Chedabucto Bay, the application of dispersants to oiled shoreline was an option to be evaluated (see Section 8.1 P. 69). Accordingly, projects were implemented to assess both the dispersing efficiencies of chemical dispersants and their toxicities. There were also other situations for which the use of dispersants was contemplated and in which toxicity was an important consideration. In reviewing the literature and product specifications it was found that toxicity data could not be compared in a meaningful way. For these reasons comparisons of the toxicity of dispersants were undertaken; results to date are reviewed later in this chapter.

6.7.1 Dispersing Capabilities

A "swirling table emulsion" test was carried out by Falk and Seto (1970) on 7 agents, with Bunker C oil and with Bunker C-seawater emulsion. In each test 2 ml. of oil or emulsion were placed on the surface of 50 ml. of gently swirling water. About 4 ml. of agent were added and the results observed after 4 hours at 5 C. The results are given in Table 6.1 below.

Table 6.1

DISPERSING CAPABILITIES OF SEVEN DISPERSANTS

Agent	Bunker C	Emulsion
Ashland Ridzlick	*	*
BP 1100	+	+
Colloid '88	*	*
Corexit 8666	*	*
Dispersol SD	*	*
Polycomplex A–11	*	+
Ezit	+	+

* no emulsification + nearly complete emulsification

Trials with Corexit 8666 in Chedabucto Bay were reported by Imperial Oil Limited (O'Connell, personal communication, 1970) as follows:

1. Corexit 8666 is only moderately effective on floating slabs of Bunker C 1/2 – 1 in. thick. Application of diesel fuel before Corexit speeds up dispersion.
2. On slicks less than 1/4 in. Corexit 8666 is effective by itself.
3. Use of Corexit 8666 on beached Bunker C followed by a hosing of sea water appears to be neither effective nor economical.

Falk and Seto also tested 4 detergents for removal of oil from polypropylene rope. Three-inch lengths of oiled rope were immersed in 8 ml. of agent for 3 1/2 hours with no agitation. The results are summarized in Table 6.2 below.

Table 6.2

CLEANING OF POLYPROPYLENE ROPE WITH DISPERSANTS

Agent	Temperature	Cleaning Action
Polycomplex A–11	21°C	None
Corexit	21°C	Nearly complete
Petrolad 1–10	21°C	Nearly complete
Dispersol SD	21°C	Nearly complete
Dispersol SD	5°C	Fair
Corexit 8666	5°C	Nearly complete

6.7.2 Toxicity Testing

Toxicity testing on a number of dispersants was carried out by Sprague (1970) at the Fisheries Research Board of Canada's Biological Station in St. Andrews, N.B. The LC_{50} (the lethal concentration for 50% kill) was determined for a number of oil/dispersant combination. The results are summarized in Table 6.3 (see following page).

Trites (1970) has rated the dispersants taking into consideration the results shown in Table 6.3 and the results of tests carried out at the Fisheries Laboratory at Burnham-on-Crouch (Simpson, 1968) and the Marine Biological Laboratory at Plymouth (Spooner, 1969) during the TORREY CANYON episode:

Corexit 8666	A
Corexit 7664	A – B
BP 1100 B (hybrid)	B
BP 1100	B – C
BP 1002	C
Dispersol SD	C
Gulf Agent 1009	C
Colloid 88	C

where A = Slightly non-toxic, 48 hour LC_{50} greater than 3000 ppm.

B = Moderately toxic, 48 hour LC_{50} between 100 and 3000 ppm.

C = Toxic, 48 hour LC_{50} less than 100 ppm.

These results show that Bunker C by itself is "practically non-toxic" (Sprague, 1970) over the span of 4 days. It is also clear that Corexit 8666 was by far the least toxic of the dispersants tested. However, a major consideration is still the dispersing power of the agent. An ineffective agent is useless and one must use much larger amounts of a dispersant having low dispersing capabilities. Indications are that BP 1100 is a much more effective agent for weathered Bunker C-sea water emulsion than Corexit 8666.

Table 6.3

Four-day median lethal concentrations of various oil dispersants, alone or mixed with Bunker C oil, to Atlantic salmon in fresh water and winter flounders and American lobsters in sea water.

	Salmon 15°C	Salmon 5°C	Flounders 5°C	Lobsters 5°C
Bunker C oil	> 10,000	> 10,000	> 10,000	> 10,000
Corexit 8666	> 10,000	> 10,000	> 10,000	> 10,000
Corexit 8666 and oil*	420	> 1,000	> 10,000	> 10,000
BP 1100B (hybrid)	110	–	–	–
BP 1100B	47	56	–	–
BP 1100 (hybrid)	< 100	< 100	–	–
BP 1100	38	30	–	–
BP 1100 (hybrid + oil*	–	< 100	–	–
BP 1100 + oil*	< 10	< 100	32	–
Gulf Agent 1009	30	–	–	–
Naptha	< 100	32 ±	–	–
Naptha-oil-talc**	1,000 - 5,000	–	–	–
Colloid 88	> 10	32 ±	–	–
Dispersol SD	18	< 1,000	< 1,000	> 1,000
Dispersol SD + oil*	10	< 100	–	–
BP 1002	18	–	–	–
XZIT x-1-11	5.6	6.6 ±	–	–

* Concentrations stated are for each of the components, oil and dispersant. Total amounts of dispersed materials added to the water would be double the indicated concentrations.

** Preliminary tests with a small sample of apparently aged mixture. Concentration based on total amount of this mixture added.

7. OIL IN THE WRECK

In late February there remained in the stern section of the wreck an estimated 40,000 barrels of Bunker C, which posed a serious threat of further spillage. Since salvage of the wreck was now impractical, the Task Force focussed its main attention upon debunkering the remaining oil. This was a difficult problem. Bunker C is extremely viscous; the cold temperatures made it even more so. In addition, the cold temperatures hampered the necessary underwater preparations carried out by divers from HMCS GRANBY. Under the direction of the Salvage Master, Sven Madsen, a plan utilizing steam injection was established for pumping the oil from the wreck. This proved successful, as evidenced by the recovery of 36,924 barrels of oil by April 11 (see Task Force Report), although an estimated 3,500 barrels was left behind (see Section 7.3.2, p. 68).

7.1 Pumping Procedures

While the Task Force debunkering operations were being successfully carried out, studies were also carried out at the Defence Research Establishment Atlantic – Dockyard Laboratory (Allen, 1970) to find methods of improving pumping rates. Two methods were examined, both of which involved the addition of heat to the Bunker C. This heat would reduce the viscosity and therefore increase the flow rate during pumping.

The first method was to inject warm diesel fuel into the Bunker C as a means of heat transfer, but no apparent mixing with the Bunker C took place. The addition of Freon-TF to the diesel fuel to increase specific gravity, and oleic acid to increase the wetting action also failed, and this approach was discontinued.

The second method was to inject steam into the Bunker C. Experiments showed that steam injection was effective in reducing the viscosity of Bunker C sufficiently for it to be easily pumped. This was, of course, verified by the success of the debunkering operations carried out by the Salvage Master. Attention thus turned to methods of optimizing the steam injection technique. Although heat transfer would best be achieved by inserting steam lines below the oil surface, it would also create problems in the connection and disconnection of steam hoses during emergencies such as severe storms. As the next best solution, an arrangement was recommended to the Salvage Master (and was utilized) in which a steam lance was welded to the spool piece just above the gate valve. This produced the best pumping rate of a number of arrangements that were examined (Payne, 1970).

7.2 Measurement of Oil in the Wreck

Some consideration was given to the estimation of the amount of oil remaining in the wreck. Such an estimate was needed to assess more fully the threat created by this oil. Moreover, a measurement technique was needed to determine accurately when the oil had all been pumped out of the wreck. A number of methods were investigated for the detection of differences in certain physical properties across the oil-water interface, namely acoustical transmission, electrical conductivity and viscosity. Because of other operational priorities, at no time were any of these methods tested. However, they may have application to some future event.

7.2.1 Acoustical Transmission

Two acoustical methods were considered. The first of these was a measurement of the reflection of acoustic energy at the oil-water interface from an acoustic source above the oil tank. However, this was not considered practical because there is little difference in acoustic impedance between sea water and Bunker C, and because the acoustic pulse would be severely attenuated in the oil.

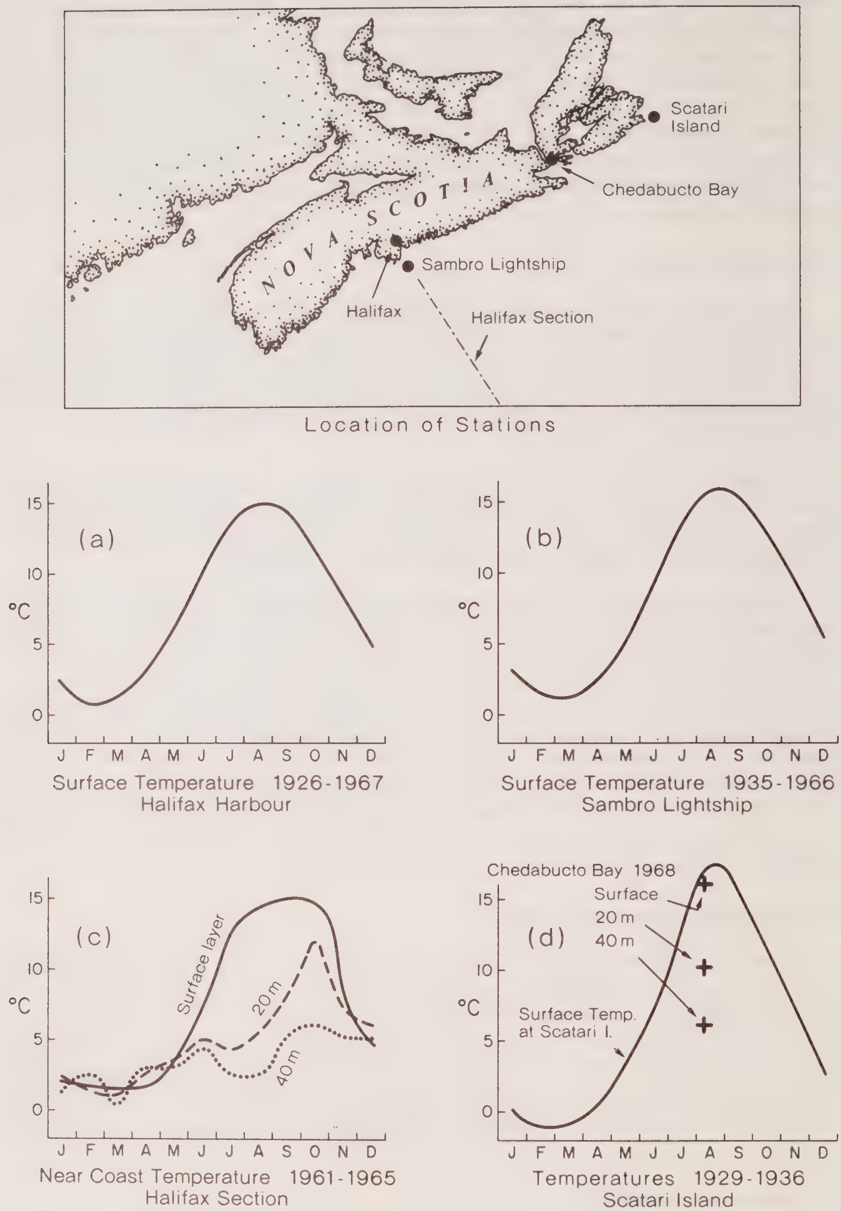


Fig 7.1 Average water temperatures along the coast of Nova Scotia, for Halifax Harbour, Sambro Lightship, the Halifax Section, and Chedabucto Bay.

An alternative method utilized the large difference in acoustic absorption between Bunker C and sea water. A pulse would be transmitted horizontally through the storage tank and reflected from a vertical interior wall back to the source. The received reflection would be much greater above the oil-water interface than below it. However, asphaltic coatings on the reflecting wall may cause critical attenuation of the signal. In addition, when the oil-water interface and the reflecting wall are not mutually perpendicular, complicated geometrical considerations must be taken into account.

7.2.2 Electrical Conductivity

One proposed method for detecting the difference in electrical conductivity across the Bunker C-sea water interface involved the lowering of a weighted two-conductor electrical lead through a small hole into the hold of the ship while the electrical resistance was continually monitored. The most serious problem appeared to be the coating of the leads during its descent through the Bunker C before it reached the sea water. One possible cleaning technique was to connect a thin resistance wire between the conductors and apply a controlled voltage to it after it was lowered into the sea water, which would cause the coating to lift off. An over-voltage would part the wire and conductivity could then be measured in the ascending mode. Alternatively, an electrical fuse could also be used. An over-voltage would blow the fuse and in so doing, blow away the Bunker C coating. A third possibility for cleaning the conductors would be the use of an explosive such as nitroso-guanadine. A final alternative involved covering the leads during descent, and utilizing a mechanical method of exposing the clean leads.

7.2.3 Viscosity

A proposed method of detecting viscosity differences across the oil-water interface utilized a fishing rod. A copper rod would be attached by its centre to a fishing line, kept in the vertical position with a thread, and lowered through a small hole in the tank top down below the oil-water interface where a quick pull would break the thread and the rod would now hang by its centre in a horizontal position. The fishing line would now be reeled in until the change in viscosity across the oil-water interface was sensed. The line would then be cut at the hole in the tank and the interface easily deduced.

7.3 Environmental Forecasting

The debunkering operations in Chedabucto Bay were influenced by the physical environmental conditions. On several occasions severe storms halted the operation completely. A number of environmental studies were therefore carried out to support tactical planning of the debunkering program.

7.3.1 Wave Conditions

On March 15 a wave recording station was installed 1.48 miles southeast of the wreck in 150 feet of water to provide wave information for the debunkering operations. The recording system consisted of a portable 75–foot tower, on which was mounted a 35–foot wave staff and pressure transducer. A telemetry system transmitted the data to the recording station 4.85 miles away at the Isle Madame Motel in Arichat. Upon completion of the debunkering operation, the station was moved towards Jerseyman Island into about 100 feet of water to support some of the environmental studies taking place. Wave recording was continued until March 23.

Analysis of the wind and wave data indicated that many of the waves were generated locally or over the Continental Shelf, except for the ocean waves which

have periods longer than nine seconds. These ocean waves, or swell, prevailed more than 80% of the time and occurred with winds from the east and southeast. The measurement of waves in Chedabucto Bay is more generally described in Section 2.5, p. 9..

7.3.2. Water Temperatures

When debunkering operations ceased on April 11, 1970, not all the oil in the stern had been pumped out. Small amounts of oil had remained isolated in corners or stuck to the walls of the tanks, and with the warming of the water had slowly moved to the top. For this reason and others (see Task Force Report), an estimated 3,500 barrels of oil still remained in the wreck at the end of June. Warmer temperatures were expected to permit more complete collection of the oil. An analysis of water temperatures was carried out (Neu, 1970) to help the Task Force in assessing the optimum period for further pumping, if this were deemed feasible.

From parts (a) and (b) of Figure 7.1 it is seen that the annual variation of surface water temperature between Halifax Harbour (an inshore station) and Sambro Lightship (an offshore station) are very similar. The annual minimums are about the same and the maximums differ by about 1°C. The times of maximum and minimum temperatures also coincide. From part (c) it is seen that at a depth of 20 metres, not only is the temperature lower, but the annual maximum occurs nearly a month later than at the surface. The temperature regime for Scatari Island (a station offshore from Chedabucto Bay) is shown in part (d), where the maximum surface temperatures occur in mid-August. Bench mark values for Chedabucto Bay (an inshore station) are also indicated. Assuming that the oil in the wreck lies at a depth of 20 metres and that the oil and water are at the same temperature, then extrapolation indicates that the maximum oil temperature would be roughly 12°C and this would occur in early September. For this and other reasons, further pumping of oil from the wreck has been scheduled for early September (see Task Force Report).

8. CLEAN-UP

Shortly after the grounding of the ARROW and the subsequent spilling of oil, it became quite evident that the clean-up of the aftermath would be a major undertaking. Eventually, nearly one-half of the shoreline of Chedabucto Bay became oiled, and small concentrations polluted the water column and the sea bottom. Fishing equipment, boats, wharves and jetties were also oiled. By mid-April when the debunkering of the wreck was completed and the Task Force priorities shifted to shoreline cleaning, no satisfactory solution had been found. Throughout Operation Oil, numerous projects were thus undertaken, many on an *ad hoc* basis, to try and find solutions to the many aspects of clean-up in Chedabucto Bay.

8.1 Cleaning of Oiled Shoreline

By the end of February roughly 190 statute miles of the shoreline of Chedabucto Bay had been coated with oil (see Fig. 3.1, p. 16). Many of the sand and gravel beaches used by the local residents and by summer visitors were unsuitable for recreation, and would likely remain so for several years (see Section 8.3 p. 75). The Task Force was faced with the difficult mission of removing the oil from these beaches and preventing further recontamination of a cleaned beach from oil moving off adjacent areas. In recent years two techniques had been widely used. In the Santa Barbara incident, heavy earth-moving equipment (bulldozers, front-end loaders and road graders) were used to remove contaminated material mechanically. On the other hand, chemical dispersants were widely used in the clean-up after the TORREY CANYON spill. The scientific coordination team assessed these techniques for use in Chedabucto Bay and provided advice as to their use by operational staff carrying out the clean-up; however, some field experiments were carried out on dispersant beach cleaning (see Section 8.1.1, P.69) and methods of stabilizing the oil to prevent recontamination (see Section 8.2, P. 74). There was also a requirement to assess the effectiveness of techniques actually used. Data would thus be obtained for use in planning clean-up operations in the event of a future spill.

8.1.1 Dispersants

The removal of Bunker C from the rocky sections of the Chedabucto Bay shoreline by physical methods is an intractable problem. In the TORREY CANYON incident, however, dispersants were used effectively on a large scale in cleaning the coastline, although considerable damage was done to the intertidal fauna.

Since the TORREY CANYON, less toxic dispersants have been and are being developed. With the urgency to find an effective method of cleaning oiled, rocky coastline and a more general need to study the effects of dispersants upon marine organisms, a field trial was carried out with one of these new products, BP1100B. Laboratory tests (see Section 6.7.2, P.61) had indicated that it was only moderately toxic and other trials had indicated that it might be effective in dispersing Bunker C.

McLean (1970) conducted a field trial on an islet on the north side of Rabbit Island in Chedabucto Bay with the assistance of personnel from Nova Scotia Technical College, Nova Scotia Department of Lands and Forests, the Marine Ecology Laboratory, the National Research Council, and the Atlantic Oceanographic Laboratory. The shore consisted of rubble beaches with a few large boulders and some exposed bedrock. Oil contamination covered a width of beach of about 15-20 feet, rather thickly, at an estimated concentration of 2-4 gal/sq. ft. of shoreline.

Fig 8.1 Dispersant beach cleaning trial on Rabbit Island. The test area, a rocky shoreline, is shown before the trial.

In the main tests a site of length 45 feet and width 15 feet was staked out and subdivided into three equal subsections (see Fig. 8.1, p. 69). At the time of the trial, May 21, 1970, the temperature of the air, sea and oil were 10, 8 and 13°C, respectively, BP1100B was applied manually at a rate of 0.09 gal/sq. ft. on two test sections and 0.13 gal/sq. ft. on the third. After a contact time of 50 minutes, the treated oil was hosed off into the sea as a brown-coloured emulsion. A high-pressure, portable fire pump was used. A wider range of dispersant exposure times had been planned but was not carried out because blockage of the hose by seaweed repeatedly interrupted hosing operations.

It was not possible to quantify the cleaning process in any way and the effectiveness of the dispersant is described subjectively. The dispersant was undoubtedly effective in removing large quantities of oil, and only flecks of oil remaining strongly adhered to the rocks, and some oil on the undersides of rocks which were not penetrated by the dispersants. Figure 8.2 shows the area after the operation. Comparison with Figure 8.1 shows the reduction of oil contamination.

Prior to the cleaning test, observations were made on the subtidal fauna immediately below the test site (Peer, personal communication, 1970). The dominant organism was *littornia* (periwinkle) which was found in an abundance of 14.4 ± 6.9 organisma/sq. ft. Chiton, starfish and limpets were also present. During the cleaning trial, dye experiments showed that the dispersed material in the water was being carried eastward along the shore rather than into the subtidal area. In this shore zone, *littorina* concentrations were 36.2 ± 25.6 organisma/sq. ft. In view of the large variance caused by clustering of the organisms, this result was not significantly different from the previous examinations before the application of BP1100B to the shoreline. There has thus been no positive indication of any harmful effects upon the flora and fauna.

It was concluded that spraying of BP1100B followed by flushing had been effective in removing Bunker C from rocky shorelines where contact between dispersant and oil was made. When contact is not made, such as underneath rocks, cleaning is not satisfactory. When contact is possible, an application rate of about 0.1 gal/sq. ft. may give satisfactory results.

8.1.2 Mechanical Equipment

For recreational purposes, the successful cleaning of beaches contaminated by oil depends upon the removal of all the oil and oiled material from the beach and the complete prevention of subsequent recontamination from adjacent areas. It is difficult ot remove all the oil with mechanical equipment because on heavily polluted beaches the oil is frequently interbedded with beach material, so that large volumes of sediment must be removed to recover a small amount of oil. In addition, there is always a certain amount of spillage, further mixing of oil and sediments, and exposure of buried oil during the cleaning operation. In Chedabucto Bay the majority of beaches are relatively small and steeply sloped. During the Santa Barbara clean-up, front-end loaders and bulldozers were found to be inefficient because of excessive spillage even though the beaches were broad and flat.

In mid-February the eastern half of the heavily oiled beach at Deep Cove, near West Arichat, was bulldozed by a contractor working for Imperial Oil Limited. This work was continued by Canadian Armed Forces personnel in early March in an initial cleaning trial; an estimated 3,000 cubic yards of sediment were removed. The northern coastline of the Bay is an erosional feature and the coastline is generally receding (see Section 2.7, p. 13). Hence with some local exceptions, sand and gravel to replenish that removed by clean-up is scarce, and excessive removal of sediment from the foreshore could lead to serious erosional problems. Daily observations of the trial cleaning operation were made by Asthana and Marlowe (1970) to monitor any changes in the beach morphology and to assess the effectiveness of the cleaning operations.

Fig 8.2 Dispersant beach cleaning trial on Rabbit Island. The test area is shown after the trial (compare with Fig. 8.1).

During the cleaning trial sediment and oil were thoroughly mixed. Subsequent trucking operations removed the bulk of the heavily contaminated sediment but the residual beach material remained thoroughly mixed with oil particles of silt and sand size. Furthermore, within several tidal cycles, recontamination had occurred.

From these short term observations, it was not possible to predict accurately the effects of bulldozing. It must be assumed that such action would upset shore equilibrium and create compensatory erosion on many of the beaches because of the scarcity of material available to replace the removed sediments, and because of the active erosion in the area. In view of the ineffectiveness of the operation and the possible damage to the foreshore, it was recommended to the Task Force on March 2 that bulldozing not be continued and that beach cleaning be confined to lighter methods such as "slick-picking" until such time as the relationship between oiling (and re-oiling) and geodynamics could be ascertained. Indeed, subsequent geological studies such as those on Crichton Island were designed with some of these questions in mind (see Section 3.4.4, p. 27).

In late April the full scale beach cleaning operation commenced. Specific beaches were designated by the Task Force for the removal of contamination. Two methods were used: (i) manual removal of oiled material from lightly contaminated beaches, and (ii) complete removal of from one to five feet of the surface material from heavily contaminated beaches using bulldozers and front-end loaders. A coastal geographer was assigned to the Task Force and he provided it with advice related to beaches to be cleaned with mechanical equipment and assessments of the effectiveness of the mechanical cleaning (Owen, 1970).

Although the final evaluation of the success of mechanical beach cleaning cannot be completed for several years, it is possible to make some comments at this time, (Owen, 1970, Loring and Drapeau, personal communication, 1970).

It was unlikely that all contaminated material could be removed from a beach area except where oil was restricted to the surface layers. In most areas the oil had been on the beach long enough so that much had been buried by the constant redistribution of sediments by wave action. Natural processes or the use of heavy machinery may re-expose this oil at a later date.

On beaches consisting of sediments coarser than sand, oiled material originally on the foreshore was moved through the action of spring storms into storm terraces on the upper parts of the beach. There may be three or more terraces of oiled material, often with a total height of more than three feet, with oiled and clean material interlayered. Crichton Island beach is a good example of this phenomenon and is being kept under observation to determine if the material will be moved and cleaned by winter and spring storms in 1971. However, deliberate cleaning of these beaches results in the removal of these terraces and of large volumes of sediment, and it appears that present methods do not remove all the oil (Owen, 1970).

When the present program to evaluate the effects of mechanical cleaning in Chedabucto Bay is completed (see Appendix A, p. 119), only a partial assessment of the effectiveness of these techniques will have been achieved. Immediately before and again after the removal of oiled materials, a series of beach profiles was made at Indian Cove (Fox Island Main), Half Island Cove, and Hadleyville; several other beaches have also been subsequently surveyed. It is intended to resurvey these beaches in 1971 to assess the rate of replenishment of sedimentary material and the extent of shoreline recession. The state of cleanliness of these beaches will be evaluated and compared with the rate of cleaning observed at Crichton Island where only natural processes have been involved in removing oil. This will permit a more accurate assessment of the degree of improvement achieved by the mechanical cleaning. Proper assessment of the effectiveness of this technique is important as it remains one of the more promising means of quickly removing oil from valuable beach areas. The evaluation will lead to a better assessment of the cost effectiveness

of the method over natural cleaningl processes and possibly to the development of better techniques and improved equipment for mechanical cleaning.

8.1.3 Recontamination

In cleaning short stretches of shoreline an assessment of the amount of oil which would move onto a cleaned area, from the adjacent shore is obviously necessary. The heaviest oil contamination in the Bay, with the exceptions of the area close to Canso and Black Duck Cove, was on Isle Madame, Crichton and Janvrin Islands, and across the west end of Lennox Passage to Rabbit Island, Evans Island and Inhabitants Bay. As of early June most of this oil remained fast on the shoreline with the exception of a substantial amount of oil moving in the Inhabitants Basin area where the "slick lickers" were recovering over fifty drums (1 drum equals 45 Imperial gallons) of oil and oiled eel grass every day. However, minor recontamination was occurring throughout the oiled areas although the amount of oil in movement was quite small compared with the situation in late February. In May, when the clean up operation got underway, the amount of oil in movement became abundantly clear. In heavily contaminated areas, within a few days of cleaning, all beaches which had been mechanically cleaned were re-oiled. The amount of re-oiling, although relatively small, was sufficient to make the beach unsuitable for recreation. Several observers (Owens, Pew, Brown, personal communications, 1970) have concluded that most re-oiling was caused by the movement of small pans and lumps of oil (usually several inches across) from rocky areas within one mile of the cleaned beach. Had a satisfactory method of stabilizing or removing the oil on these rocky areas been available, much of the recontamination could have been prevented, (see Section 8.2, P. 74). Recontamination also occurred during the mechanical cleaning operation. As the bulldozer or front-end loader moved along the shore, the oil which was displaced tended to move onto the water and was subsequently redeposited in small amounts on the recently cleaned areas.

8.2 Stabilization

As the ambient temperatures rose, the oil on the shoreline became increasingly more mobile and was causing recontamination of adjacent (less than several miles) clean shoreline. It appeared that many months would be required before the natural processes would sufficiently immobilize the oil to reduce this source of contamination to a negligible level. Accordingly, the option of stabilization of the oil in situ acquired a considerable degree of urgency and a program was initiated to assess means of exercising this option.

Laboratory experiments were conducted (Whiteway, 1970) to investigate the properties of various inexpensive powders as stabilization agents under the conditions that would be experienced in Chedabucto Bay (suggested by Puddington, personal communication, 1970). In separate tests, limestone, plaster-of-Paris, alumina, magnesia, graphite and talc were applied to oil for five hours at 40°C. Coarse powders yielded gritty, crumbly deposits and fine powders greasy ones. In particular, limestone gave a dry, non-greasy deposit.

A series of tests with different sizes of magnesium oxide powder was conducted (see Table 8.1 below) to demonstrate more clearly the effect of particle size. Applications were for 13.5 hours at 40°C.

TABLE 8.1

STABILIZATION WITH MAGNESIUM OXIDE POWDER

Average Particle Size	Weight of Powder / Weight of Oil	Character of Deposit
0.0250 cm	4.1	Crumbly
0.0150 cm	2.8	Cohesive
0.0100 cm	2.2	Cohesive
0.0075	1.2	Greasy

Time and temperature also proved to be important factors in the stabilization process. Tests carried out with limestone at 6°, 25° and 40°C indicated that the degree of absorption increases with temperature, while in respect to time absorption seems to level off after 10-15 hours. These tests indicated that the powder must be applied when the oil is at a relatively high temperature, say 25°C, a temperature well exceeded on a hot, sunny day.

The manual application of limestone was attempted in Chedabucto Bay in early May. Limestone was used because laboratory tests had indicated that it might be satisfactory yet inexpensive. Other materials may be chemically better; (for example ferric chloride may be a good hardening catalyst (Wiles, 1970) but evaluation of such materials would require long term experiments.

These early trials were unsuccessful as the ambient temperature was only in the neighbourhood of 10°C. Moreover, a grey skin had formed on the oil, the result of weathering and polymerization. (see Section 4.3, p. 40). Further small scale field trials in mid-June were more successful, but a method was needed of getting to oil that had formed a grey skin or was lying between and under boulders. Experiments with a modified sand blaster were unsuccessful. As with many of the other problems of clean up, spped is essential, before the oil weathers and polymerizes or gets into inaccessible locations. For a spill in warm temperatures, providing action is taken quickly, the manual application of limestone may be a feasible and economical method of stabilizing the oil on the shore, but more experimentation is required to assess this more accurately.

8.3 Natural Cleaning

The application of mechanical and manual methods to heavily oiled beaches (see Section 8.1, p. 69) is only a start to the process of total cleaning. The real completion will be achieved by nature and may take several years or more. Accordingly, we have given consideration to two natural processes, self-cleaning and biodegradation.

8.3.1 Self-Cleaning

During reconnaissance studies (Asthana and Marlowe, 1970, and Drapeau, 1970) observations on self-cleaning were made as follows:

(1) With the intimate incorporation of oil with shore material, the rate of self-cleaning is dependent upon the local geodynamics, i.e. shorelines exposed to surf action clean up more rapidly than those in protected areas behind bars or spits, or in lagoons (see Fig. 8.3, p. 76).

(2) The rate at which oil disappears is inversely proportional to the size of the sediments, so that sand beaches clean up more rapidly than boulder and bedrock shorelines under similar surf conditions (see Fig. 8.4, p. 77).

Fig. 8.3 Self-cleaning, Black Duck Cove, March 24, 1970. The area in the fore-ground has been cleaned by the surf, while the area on the point, protected from the surf, remained oiled.

Fig. 8.4 Self-cleaning. Fox Bay, March 24. The boulder remains oiled, although the oil is slowly flowing, but the sand has been cleaned during the previous tidal cycle.

Fig. 8.5 This sand beach has been completely impregnated with oil and paralyzed. Black Duck Cove, March 24, 1970.

Fig. 8.6 The collection of oil on the surface of the water in a tidal pool, Fox Bay, March 24, 1970.

(3) Sand beaches can receive oil and rapidly clean themselves up to a certain threshold depending upon local conditions, beyond which they become paralyzed and remain polluted like boulder and bedrock beaches. The paralyzed beaches (see Fig. 8.5, p. 78) are mainly those where oil has deeply impregnated the sand and those located on the inside of lagoons.

(4) Inspection of oiled bedrock and boulder shorelines revealed a small but significant flow of oil off these surfaces when the tide was ebbing. Some of this oil flows into crevices in the interstitial areas between individual boulders and into small tidal pools (see Fig. 8.6, p. 79). During flood tide some of the redeposited oil floats off, either to be carried out to sea or to recontaminate the shore material. The flow of oil which has been recorded by time lapse photography on the shores of Chrichton Island (see Section 3.4.4, p. 27) apparently depends upon the nature and slope of the surface, the amount of direct solar radiation and the ambient temperature. A study of the effect of temperature upon the flow of oil on the shoreline is continuing (Pew, personal communication, 1970).

8.3.2 Biodegration

The literature on the degradation of oils by micro-organisms is notably lacking in information on biodegradation in cold sea water and in the case of Bunker C, a literature search failed to turn up any relevant work. Thus in the ARROW situation there existed no sound knowledge upon which to base an estimate of the role of biodegradation in the eventual fate of the Bunker C in Chedabucto Bay.

Such knowledge is, for example, a necessary ingredient in arriving at an estimate of the time scale involved in the clean up of oil by natural processes alone. It is also vital in assessing the practicability and safety of possible microbiological measures to speed up the natural process of biodegradation. Kinney, Burton and Schell (1969) concluded that in Cook Inlet, Alaska, with water temperatures of about 5°C, biodegradation reduced the concentration of crude oil in the water by 90% in about two months while tidal flushing required four to five times as long for comparable reduction. Thus it is seen that even under such relatively cold conditions, biodegradation may play a dominant role in determining the rate at which clean up proceeds by natural means. For some part of the year many of the coastal waters of Canada are covered with ice, a greater percentage experiences water temperatures at or near the freezing point. There is a very evident need for extensive basic and applied research on biodegradation of oil in cold and ice-infested waters.

Many aspects of microbial degradation in the sea require further study. Due to the chemically diverse nature of oil, a complex mixture of micro-organisms would be required for significant degradation since different molecular species of hydrocarbons are vulnerable to different organisms. In the range -1.8°to 5°C the number of possibilities of microbes which function at low temperatures is relatively restricted. In addition, other characteristics of the environment would also affect rates of growth and rates of degradation. For example, indications are that the nitrogen and phosphorus concentrations in the sea would be marginal for the support of a large and actively growing microbial population (ZoBell, 1970).

Such basic studies should lead to a sound appraisal of the feasibility of large scale introduction of microbe cultures into a polluted environment to hasten the natural process of biodegradation. Quite obviously, a firm assessment of the pathogenic hazard to the biota resulting from such a manipulation of the environment must first be determined.

In Operation Oil some thought was given to a proposal (Zajic, personal communication, 1970) for conducting a small scale field trial of microbial shoreline clean up to take advantage of the existence of oiled shoreline in Chedabucto Bay at sites which appeared suitable for such purposes. The proposal was dropped when

further investigation raised uncertainties in respect to many of the considerations discussed above.

The impetus of the ARROW incident has already resulted in some new research interests on biodegradation in the cold marine environment. The Fisheries Research Board of Canada (Stewart, personal communication, 1970) has initiated a project designed to take advantage of the opportunity presented by the situation existing in Chedabucto Bay. Water, beach and bottom samples are being collected for study under controlled laboratory conditions simulating as closely as possible under controlled laboratory conditions known to exist in the Bay. Other agencies concerned with the dearth of knowledge about biodegradation of oil in the environment, for example the U.S. Federal Water Quality Administration, are promoting some projects in the field. Nevertheless, it is apparent that the subject is so complex and so little investigated that if offers many challenging opportunities for imaginative research.

8.4 Cleaning of Contaminated Fishing Gear

Following the spillage of oil from the ARROW purse seining operations continued in the Bay on an extensive scale. Early in February, two seine nets were fouled with oil, with two more fouled shortly thereafter. It was anticipated that gill nets, lobster traps, and other types of fishing gear might also present a problem. What was needed was a quick and efficient method of cleaning fouled gear so that it could be returned to service promptly. The huge size of a seine net (approximately 2000 x 300 feet) presented the major challenge.

A number of experiments were carried out on the cleaning of nylon and polypropylene rope. Wiles (1970) tested some petroleum-based solvents and commercial detergent emulsifiers and concluded that polypropylene rope was most easily cleaned with Varsol. Falk and Seto (1970) also tested a number of dispersants. Wallace (1970), of the Department of Fisheries and Forestry, tested a number of solvents, and also concluded that Varsol was best for net cleaning. At the Atlantic Oceanographic Laboratory, Jamieson, Gibson and Myrick (1970) tested 12 household detergents, but none was successful.

Trials at a local Halifax dry-cleaning establishment showed that dry-cleaning was effective in cleaning nylon and polypropylene. However, some components of fishing gear, such as plastic and styrofoam floats fitted to nets, were not compatible with this process.

Steam cleaning, because of its non-chemical nature, was also examined. A test was carried out at the Atlantic Oceanographic Laboratory on a section of freshly oiled nylon twine seine net, in which steam cleaning was found to be very effective in removing the oil.

On the basis of this information a laundromat was designed (Jamieson, Gibson and Myrick, 1970) by a team involving personnel primarily from the National Research Council, The Atlantic Oceanographic Laboratory, the Defence Research Establishment Atlantic, and the Department of Fisheries and Forestry. It was constructed (Gibson, 1970) by Ferguson Industries Limited, Pictou, Nova Scotia, and installed at a site adjacent to the Nova Scotia Power Commission's Thermal Generation Plant at Point Tupper which provided the required supply of steam. Total elapse of time from the date of the design proposal to installation was only three weeks. It was designed as a 3-phase operation, namely (1) steam cleaning, (2) degreasing, and (3) warm water flushing.

The degreasing solution consisted of one part of Cody's degreaser mixed with four parts of diesel oil (Myrick, 1970). While tests mentioned above showed Varsol to be more effective, further tests showed the degreaser diesel oil mixture to be adequate for the job at a lower cost and with a reduced fire hazard. Steam at a pressure of 185 pounds was obtained from the Power Commission. A steam coil was

also used to heat the degreasing solution. Warm flushing water was also obtained from the Power Commission.

The first net to be cleaned was a herring seine from the PIERRE HELENE. This net, 1950 feet long and 252 feet deep, was the smallest of four that were cleaned and was easily handled by the power block. Auxiliary pull was needed to drag the other larger nets through the laundromat. In the steaming operation, very little oil appeared to be removed from the first net, possibly because the net was tightly compacted and also because the oil had been on the net for a long time and had weathered. Steaming of the other nets was more successful. The degreasing phase was very effective. In the final stage, the warm water and residual solvent formed an emulsion and was flushed out as effluent. The nets emerged essentially clean and undamaged, to the satisfaction of the owners.

A variety of smaller nets and lobster fishing gear were also cleaned. When debunkering operations were completed polypropylene rope, gate valves and other equipment from the Irving barge WHALE required cleaning. In June several thousand feet of badly oiled T-T boom were also cleaned.

All in all, despite the need for improvements and refinements, not unexpected in such a crash project, the laundromat successfully served its intended purpose. Nets were cleaned and returned to service in far less time and at substantially lower cost than replacement with new nets through a claims procedure. The capital cost of the laundromat was about $26,000. The value of a single seine net is about the same and thus with the successful cleaning of the first net, the capital cost of the plant was almost recovered. Operational costs per net were estimated at only $2,600 (Myrick, 1970).

8.5 Steam Cleaning of Jetties

The large number of heavily oiled jetties in the Chedabucto Bay area constituted a minor threat to marine traffic using those facilities. Accordingly, Towne Building Services, Truro, N.S. contracted to carry out steam cleaning of oiled jetties. This method was attractive because it was simple, reliable in adverse weather, and did not require the use of chemicals.

Steam cleaning was performed with portable steam cleaning equipment mounted on a catamaran (Magill, 1970). A rate of 240 ft^2/hr. was achieved. As the removed oil fell into the water, peat moss was applied as an absorbent and was then recovered with dip nets. The only major difficulty was the rising and falling of the tide. Areas near the low tidal mark were not always accessible and often required a second sweep at the next low tide. In conclusion, steam cleaning appears to have been used effectively in cleaning oiled jetties in Chedabucto Bay.

9 Conclusions and Recommendations

9.1 General Remarks

Obviously the best cure for oil pollution is prevention. However, the options open in this regard were greatly reduced by the end of the first week after the grounding, for by that time about one half of ARROW's cargo had excaped to the sea. While the principal concern was to deal with the looming threat of further serious spillage from the intact portions of the wreck, nevertheless, the contingency forces were faced with an array of intractable problems demanding immediate attention as a consequence of the large amount demanding immediate attention as a consequence of the large amount of oil already out of hand. It was these problems which engaged the bulk of the scientific effort and consequently the conclusions and recommendations of this report deal mainly with the consequences and clean up of a spill, rather than with prevention. The short term nature of the immediate task made us painfully aware of the fact that really effective solutions to most of the scientific and technical problems posed by such disasters require continuing research, development and evaluation.

The ARROW disaster revealed dramatically and at substantial cost the woefully inadequate measures in being for contending with oil spills of this magnitude. Aside from underlining the already recognized need in Canada for an approved contingency plan (a plan was in the draft stage at the time of the accident) and for a well-trained emergency organization capable of immediate response, it emphasized the still primitive state of the technology of recovery and clean up. While the governments of several countries and the industry are devoting resources to the development of this technology, it is fair to say that, by and large, there is a long way to go before really practical and effective emergency systems are in use. If the challenge of spills of oil, or indeed of any hazardous material, is to be faced squarely, then a response analogous to that of fire brigades is mandatory. In the research and development aspects of this process there are roles, notably those related to cold environment, in which Canada should not only be more actively engaged, but indeed out in the forefront.

While the situation within Chedabucto Bay absorbed most of our effort, attention was given to the fate of oil on the high seas. The quantity of oil in transit liberated annually to the sea, intentionally or inadvertently, has been estimated at about one million metric tons (Blumer, 1969) or about 100 times the amount of oil released by the ARROW. Of this less than 20% can be attributed to major accidents. The estimate does not include oil from other sources, such as ships' bunkers and underwater production. As a matter of perspective, it is well to emphasize that the threat of oil pollution to the high seas appears to arise more from the many minor spills than from the highly publicized catastrophes. Moreover, even relatively small amounts of oil may be transported great distances while remaining identifiable as oil. For example, in the case of the ARROW, of the 10,000 tons of oil released, an unknown fraction, probably less than half, escaped to the open sea, mostly during the first week or two. Yet the 20-mile length of the north shore of Sable Island, located 100 nautical miles seaward of Cerberus Rock was contaminated, albeit lightly, by oil from the ARROW. Oil was also observed in dispersed particulate form in a band several miles wide extending westward for 120 nautical miles along the coast of Nova Scotia (Section 3.2, p. 17). Oil in the high seas may be a widespread phenomenon deserving much more attention than it has received to date. We return to the subject in Section 9.9, p. 89.

Finally it should be emphasized that the conclusions and recommendations of this report should not be construed as a complete compendium of every aspect of oil pollution requiring research and development. The intention is to present a selection

of problem areas, some quite specific, others rather general, which, on the basis of experience in Operation Oil, appear particularly to warrant new research or development attention, and to have some special relevance to Canada.

9.2 Organization for Research, Development and Evaluation

The experience of "Operation Oil" has underlined the vital need for a permanent evaluation unit within the agency designated to be responsible for dealing with spills of oil and other hazardous materials on seas, lakes and rivers. The unit would provide focus, coordination and planning for a national program of research, development and evaluation aimed at improving the techniques of contending with future incidents. Extensive work related to oil spills is underway in Canada and elsewhere in the world, notably in the United States, United Kingdom and Western Europe. The unit would be in close touch with the practioners of the work and well informed about the growing fund of knowledge and associated system developments with a view to selective adaptation to the Canadian situation. It would promote and arrange for the conduct of research and development in Canadian universities, government laboratories or industry. This would be a selective program centred on those aspects of the general problem in which Canada is or should be particularly expert – oil spills in ice-infested waters are an outstanding example. A staff of 3 to 4 professionals (engineers and scientists) is suggested as appropriate for a program of this breadth.

9.3 Recovery from a Vessel

If salvage of the ship complete with cargo is not feasible, the first line of defence is obviously to recover the cargo. Existing conventional methods are very unlikely to be applicable except in the rare case where the accident has occurred in some sheltered spot, handy to salvage facilities and with little damage to the ship. A specially designed, well-proven and easily deployable, allweather system for cargo recovery must be developed. The U.S.C.G. has conducted trials recently on a prototype of an air-droppable system (Montgomery, 1970). Operation Oil developed and demonstrated by recovery of 37,000 bbls. a system of pumping heavy Bunker C from a submerged wreck with sea temperature near the freezing point and air temperatures often well below freezing. The system and its operation are described in the report of the Task Force. Underpinning the operation were the divers of HMCS GRANBY, the Halifax-based diving establishment of the Canadian Armed Forces. Their remarkable feats of endurance and skill were of critical importance to the successful debunkering of the stern section.

Recommendation

Future Canadian development work on recovery systems should link the cold environment experience gained in Chedabucto Bay with the existing work on highly deployable systems with the objective of realizing equipment which could be deployed effectively under severe winter conditions including those in the polar regions. The two central problems are the pumping-out system and the provision of containers large enough to receive the oil – the requirement could exceed one million barrels.

9.4 Containment and Recovery from the Water

It is very likely that even in incidents in which recovery from the wreck is feasible, there will be more or less large scale leakages of oil onto the sea. Leakage from an underwater well or pipeline presents an analogous problem. The logical countermeasure from the point of view of the protection of the environment is to contain and recover the oil in the vicinity of the source, but existing systems are far from being generally adequate. Despite a considerable amount of development in recent years there is as yet no booming device which has proved capable of retaining oil in the presence of any significant sea state or swell, i.e. about sea state 3 or higher. The

same can be said about devices for recovering the contained oil from the sea surface. Again, there is also the problem of having something at hand into which the oil can be put.

9.4.1 Booms

In Operation Oil some progress was made towards the development of a boom suitable for use with heavy oil in rough water and strong currents. Experiments showed that a fine mesh seine net (5/8 inch mesh) retains cold Bunker C almost completely; the addition of an absorbent, peat moss, improved retention. An experimental net boom was constructed 2,000 feet in length, 30 feet in depth and with a float arrangement that supported a foot or two of the net above the surface. This above-surface clearance is probably insufficient for higher sea states. The net proved relatively easy to deploy by essentially standard seiner techniques. Its flexibility and deep skirt should make if effective in relatively strong currents and rough conditions, but this was not demonstrated by field trial in Operation Oil. Its behaviour as a boom for crude oil also needs to be evaluated; in this case an absorbent will likely be required to minimize movement of the crude through the mesh. Nevertheless, it is judged to have considerable potential. Boom development was also carried forward by the operational forces in the field resulting in a conifer brush boom which proved quite effective for currents above one knot and at least sea state 3. The experience with both seine net and conifer brush points the direction for research to permeable rather than impermeable booms.

Recommendation

It is therefore recommended that further feasibility studies be undertaken to evaluate the possible applications of permeable booms with particular emphasis on their potential for containing oil spills in open water; these studies to be followed, if warranted, by system design, development and large scale field evaluation of an operational prototype.

9.4.2 Recovery from the Water

During the clean-up phase in Chedabucto Bay considerable experience and success was had with recovering oil and oiled material from the sea surface using an Oleovator (usually called by the less elegant but more descriptive term "slick-licker"), developed by Sewell (1970). The machine was in an early stage of development and suited for use only in sheltered locations. Working in a thick continuous slick it could recover oil at 45 Imperial gallons per minute. With only relatively minor further development it should become a valuable stock tool for clean-up of small scale spills in harbours or other quiet water situations. With major development it may well have application in open sea situations.

Recommendation

Making full use of the experience gained in Chedabucto Bay with slick-lickers, a system study, followed if warranted by development and evaluation, should be undertaken to the end of acquiring equipment capable of recovering oil from a contained pool in a sea state at least as high as that limiting the effectiveness of the containing boom.

9.4.3 Peat Moss as an Absorbent

Peat moss was shown to be a very effective absorbent of beached or floating Bunker C oil provided it was used within about the first two weeks of the oil having been released. The mixture of oil and peat moss proved considerably easier to remove from beaches than the oil alone, and was readily recoverable from the water surface by "slick-lickers", see Section 6.3.2, p. 56). It also gave promise as a means of improving the oil retention of permeable booms. Field trials demonstrated it to be more effective at temperatures around 0°C than other low cost absorbents such as

straw. Other advantages are that peat moss is available in large quantities from sources often close to where oil is most likely to be released into Canadian waters, that it can be stockpiled without its efficiency deteriorating, and that its effectiveness is not greatly affected if it is used wet, or even, having been wet, is used frozen. However, the process of oil absorption and retention by peat moss is not well understood.

Recommendation

Further research should be undertaken on the effects of temperature, water emulsification, "weathering" and other parameters on the mechanism of oil absorption by different forms of peat moss.

9.5 Burning

If recovery is not feasible, the only remaining operation that could remove the oil from the water is burning. It is not an easy thing to do, and there are such constraints to be considered as air pollution and fire hazard to nearby structures on the shoreline. From a review of the state-of-the-art and from the limited experiments on burning in Chedabucto Bay, it appears feasible to burn fresh Bunker C slicks if certain conditions are met (see Section 6.4, p. 56), but for it to be a practical operation, major advances must be made in the techniques of containment, ignition and maintenance of combustion (wicking agents). When the oil is converted to the characteristic water-in-oil emulsion, which happens within hours or at most in a few days, it becomes incapable of supporting combustion either floating on water, or beached.

Of particular concern to Canada is the pervasive threat of major oil spills in ice-infested waters. In that event it is conceivable that the presence of ice could be an advantage in the sense of providing non-inflammable containment and quiescent conditions in which the emulsification of oil would be retarded. If it can be shown that heavy oils will support combustion under these circumstances, an important gain will have been made in the restricted options applicable in ice, as for example in the Arctic.

Recommendation

Feasibility research on burning should be undertaken in Canada under a series of field conditions representative of the various types of ice situations to be found in the more important waterways.

9.6 Dispersal and Sinking

Putting the oil on the bottom by the application of sinking agents or disposing of it into the water mass by dispersant techniques does not, of course, remove it from the water environment. On the contrary, the oil, albeit in a diluted form, is placed in far wider contact with the marine biological system creating a potential ecological threat, the nature of which is largely unknown. In the light of these considerations and because a primary objective of the Task Force was the protection of the fishing industry in the area, dispersants and sinkers were not used in Chedabucto Bay.

On the scientific support side, while no work was done on sinkers, comparative laboratory studies were carried out on the toxicity of a number of commercially available dispersants, see Section 6.7.2, p. 61. The relative effectiveness of certain dispersants for shoreline cleaning was also investigated by both laboratory and field trials, see Section 8.1.1, p. 69.

Recommendations

(a) Dispersants, in varying degrees, are toxic substances in the water environment. Manufacturers have sought accredited toxicity rating and approval of their products by government but, at present, in Canada, no agency of government appears to

have the responsibility or authority to test and approve dispersants for use in Canadian waters. It is recommended that this control function be assigned to an appropriate agency as an integral part of the national contingency plan to combat oil spills.

(b) Observing that much development work is going into the formulation of more effective and less toxic dispersants and that there is growing concern about the lack of knowledge as to the effects on the ecosystem resulting from their use, there is a clear need for biological research to provide fundamental information and guiding principles upon which to base an intelligent judgment on the proper use of dispersants, whether on floating oil in open water or in confined waters or on beached oil for shoreline cleaning.

9.7 Shoreline Problems

It can be safely anticipated that despite the best of intentions and the availability of improved techniques, there will be incidents in the future in which measures to control the spill fail to prevent serious contamination of a shoreline. Depending upon the location and character of the shoreline, a contingency authority will be faced with the formidable array of tactical and technical problems that has characterized all the recent major oil spills involving large scale shoreline fouling, and will be looking for significant new solutions to these problems. While it cannot be said that Operation Oil produced any "breakthroughs" in shoreline clean-up technology, the fund of experience and knowledge gained should have important application in contingency planning against future incidents. Among the more important contributions are those arising from the unique experience with a major spill of Bunker C on water at the freezing point and involving the movement of the oil into ice fields and onto frozen shorelines. Specific technical contributions are reported in several of the preceding chapters and those on the operational side are discussed in the report of the Task Force.

Out of this experience three problems are judged to stand out as particularly warranting further research attention – the biological effects from chemical cleaning of the shoreline, in situ stabilization of beached oil and biodegradation as a shoreline clean-up technique.

9.7.1 Biological Effects from Chemical Cleaning

The use of dispersants is one of the few options available for shoreline cleaning. Certain dispersants are effective cleaning agents for beached heavy oils and no doubt they can be further improved. However, as the process involves washing the resulting emulsion into the water, there arises the question of the significance of the possible effects on the biota in the water. It is a serious question especially where large scale use of dispersants is contemplated. In many cases, because of the absence of sufficient knowledge upon which to make a reliable judgment as to the probable biological consequences of the use of dispersants, the otherwise promising dispersant option has to be discarded. Indeed, there is a growing tendency to ban their use except under limited and specified circumstances – such a restriction is incorporated in the National Oil and Hazardous Materials Pollution Contingency Plan prepared by the United States Council on Environmental Quality, 1970. It is evident therefore that there is a need for considerably more research directly related to this problem than is presently in progress. It is, of course, a very difficult problem covering several fields of research involving the whole complex of the biological cycle and the behaviour of the associated physical environment.

Recommendation

Encouragement should be given to research projects which would provide a sound

basis for the establishment of relationships between levels of dilution of oil/ dispersant emulsions and significant biological effects in the water environment.

9.7.2 Stabilization of Beached Oil

The original intention from an early stage of Operation Oil was to restrict shoreline cleaning to jetties, harbours and a number of recreational and community beaches, on the assumption that by late spring when the work would be undertaken, recontamination from adjacent oiled areas would not be a serious problem. In the event, this is proving generally to be the case, although recleaning has been required in several instances and a clean-up crew is being kept on throughout the summer to take care of new incidents of recontamination.

Even after four months of weathering, much of the beached oil has remained fluid and, aided by heat from the sun, is found to move onto the water whereupon it is transported to another site. An economic means of stabilization of the beached oil sufficient to prevent this movement could make an important contribution to reducing the cost of shoreline clean-up. It also would provide another viable option to an on-scene commander faced with the usually recalcitrant problem of what to do about beached oil. Of several possible methods investigated (Section 8.2, p. 74), the application of agricultural limestone, inexpensive and commonly available, showed some promise, but at the time of writing, field evaluation is incomplete.

Recommendation

A program of applied research and evaluation should be undertaken with the aim of developing an economical and practical technique of stabilizing beached oils *in situ.*

9.7.3 Biodegradation of Beached Oil

The process and, in particular, the rate of the process involved in the decomposition of beached oils by microbes is virtually unknown. As to studies of the process at low temperatures, no references at all could be found in literature. Simply as an aid in judging how long natural processes would take to clean-up a given shoreline, such information would be valuable. But there is also the possibility that the natural process of biodegradation could be safely accelerated, for example, by the application of appropriate cultures and nutrients. While as a result of the impetus of the ARROW disaster one study is underway on microbial cultures derived from samples of water and beached oil taken from Chedabucto Bay (Section 8.3.2, p. 80), there are obviously many other scientifically challenging aspects of this complex subject awaiting attention.

Recommendation

Researches should be initiated to investigate the nature of the biodegradation process in beached oils as it occurs under natural conditions, especially at low temperatures, and also to assess, on a laboratory scale, the feasibility of deliberate acceleration of the process as a potential new method of clean-up.

9.8 The Physical and Chemical Properties of Oil Exposed in the Marine Environment

In dealing with an oil spill the availability of knowledge about the physical and chemical behaviour of the oil upon exposure to the sea often plays a vital role in tactical decisions and the choice of options. It was the experience in Operation Oil, as it was in the TORREY CANYON, that the desired knowledge, for the most part, did not exist in the litertature. Typical questions to which no satisfactory answers could be given were: What are the characteristics of the spreading process from bulk oil to invisible film and how is it affected by sea state, currents and wind? How much oil goes into solution with the sea water? What is the mechanism and rate of production of the particulate oil found in the water mass? What is the mechanism

and rate of formation of the water-in-oil emulsion and what are its physical and chemical properties as they relate to possible clean-up procedures?

In response to this situation a crash program was organized, involving several laboratories, to acquire the more critically needed data on the properties of the ARROW Bunker C itself and of the water-in-oil emulsion which forms within a few days after the oil has spread upon the sea. The results obtained to date of writing are summarized in Chapter 4. This *ad hoc* program, while making some significant contributions to the general fund of knowledge in this field, could only scratch the surface of the many interesting and important problems needing research in depth and which appear to be neglected in the existing literature.

Recommendation

Accordingly, a vigorous coordinate program should be promoted for research on the physical and chemical properties of petroleum products, especially crudes and heavy bunker oils, that have been exposed in the marine environment. Of particular interest are the properties or process of spreading, solution, particle formation, emulsification and weathering. Observing that the subject appears to be receiving increasing attention elsewhere, a Canadian program should concentrate on unique aspects, for example, those related to Arctic conditions.

9.9 The Fate of Oil in the Open Sea

In the first section of this chapter certain observations in connection with the ARROW incident were related to the proposition that oil in the high seas may be a widespread phenomenon deserving of much increased attention. There is a growing body of evidence from the North Atlantic and the Mediterranean which supports this proposition. For example: Horn et al (1970) observe that "Taken all together our observations indicate that lumps of petroleum exist in surprisingly large amounts on the sea surface. These lumps form a chronic type of oil pollution which may significantly affect the marine ecosystem.". From his papyrus craft sailing the trade wind route to the West Indies, Heyerdahl is reported to have observed many times asphalt-like lumps, ranging from the size of rice to that of potatoes. There is a persistent and perhaps increasing amount of weathered oil around Bermuda (Arnell, personal communication, 1970), which appears to be of pelagic origin rather than from local sources. Dead oiled sea birds of species whose normal habitat is the open sea have been found repeatedly in large numbers along the east coast of Newfoundland (Tendron, 1968), which taken in conjunction with the fact that large fleets of vessels from many countries fish the Grand Banks, suggests that there may be significant evidence of oil pollution in this region.

It is evident that a concerted research by interested oceanographers from around the world will be required to assess quantitatively the distribution of oil on and in the ocean, to understand the physical, chemical, biological and microbiological processes involved in its dispersion and eventual disposition and to estimate the effects on the marine ecosystem if the ultimate objective of evaluating the true level of this pollution threat is to be attained. In the absence of such an evaluation, preventive measures are all too likely to be either inadequate or unnecessarily restrictive. It is an aspect of the fundamental issue – the solution of the conflict between the need to maintain the quality of the environment upon which mankind ultimately depends and the massive, ever-increasing demands made upon the environment.

Recommendation

Canadian oceanographic research organizations, especially those concerned with the Atlantic, should map out and implement programs to participate in this international problem – the fate of oil in the sea. It would appear that the Northwest Atlantic area presents its own special challenges: Is the heavy concentration of fishing vessels on the Grand Banks a source of endemic oil pollution of long

standing and, if so, how is it distributed, and have the oil-consuming species of bacteria established populations as in the Santa Barbara, California, area? If the promise of large producing oil fields on the Atlantic shelf of Canada is fulfilled, it will be of the greatest importance to have an assessment of the present level of oil contamination in the area prior to any significant spill that may occur from these fields. Bermuda, strategically located from an oceanographic point of view, may offer special advantages as a mid-ocean monitoring station for pelagic oil pollution in the Northwest Atlantic, and consideration should be given to arranging a cooperative program with the Bermuda Biological Station.

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Provincial Agencies

Nova Scotia Agricultural and Marketing Department

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Most of the references cited are to unpublished reports and while some will be published many will remain in their present status. A complete collection of this unpublished documentation is being kept on file at the Bedford Institute and in the event that a report is not available from the originating agency or individual, a copy may be obtained from the Librarian, Bedford Institute, Dartmouth, Nova Scotia, upon request.

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In addition to the above references, a number of personal communications have also been cited in this report. As a further aid to those who may wish to obtain more detailed information on the various aspects of Operation Oil, the personal communicants and their respective affiliations are listed below:

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APPENDIX A

CONTINUING RESEARCH PROGRAMS

(as of July 1970)

There is clearly a need for further research in virtually all aspects of oil pollution. The short term *ad hoc* activities have already been incorporated into the various parts of this report. However, a substantial amount of longer term scientific and technological activity has also been undertaken, and in many cases such activity has not yet been completed. A list of continuing research projects (as of July 1970) is given below. Some of these projects have been in progress since February, while others have only recently been initiated. Indeed, it is expected that the momentum of Operation Oil will continue to bring about further research activity in this field.

Project	Agency	Scientist in Charge	Completion Date
1. General water circulation in Chedabucto Bay, N.S. Current metering, salinity and temperature data taken in Chedabucto Bay are being processed and interpreted.	Atlantic Oceanographic Laboratory, Dartmouth, N.S.	H.A. Neu	October 1970
2. Geological and Ecological studies of Crichton Island, N.S. - Studies of the effect of oil and oiled sediments on beach morphology, the rates of natural cleaning, and the effect on the biota.	Atlantic Oceanographic Laboratory, Dartmouth, N.S. and Marine Ecology Laboratory, Dartmouth, N.S.	G. Drapeau M.L.H. Thomas	continuing into 1971
3. Geological Evaluation of Mechanical Beach Cleaning in Chedabucto Bay, N.S. Topographic profiles have been taken	Marine Sciences Branch, Ottawa, Ont.	E.H. Owens	August 1970

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before and after beach cleaning operations. An evaluation of the effectiveness of these methods will be made.			
4. Geomorphological Features of Chedabucto Bay, N.S. Charts of the geomorphological features of the Bay and of the extent and degree of oil contamination (as of July 15, 1970) will be compiled.	Marine Sciences Branch, Ottawa, Ont.	E.H. Owens	August 1970
5. Oil in the Bottom Sediments in Chedabucto Bay, N.S. Analysis and interpretation of 60 sediment samples from the floor of the Bay is continuing.	Marine Ecology Laboratory, Dartmouth, N.S.	D.H. Loring	September 1970
6. Particulate Oil in the Waters of Chedabucto Bay, N.S. (1) A study of the distribution and movement of oil particles in the water column in the Bay is continuing, for particles in the 0.1 to 1.0 mm size range.	Atlantic Oceanographic Laboratory, Dartmouth, N.S.	W.D. Forrester	September 1970
7. Particulate Oil in the Waters of Chedabucto Bay, N.S. (2) A study of the distribution in the Bay of total particulate matter in the 0.01 to 0.1 mm size range, and the oil content in the water.	Marine Ecology Laboratory, Dartmouth, N.S.	R.W. Sheldon	August 1970
8. Measurement of Oil in Sea Water	Atlantic Oceano-	E.M. Levy	Continuing

Project	Agency	Scientist in Charge	Completion Date
A shipborne method is being developed for the measurement of oil in the particulate and dissolved forms present in sea water.	graphic Laboratory, Dartmouth, N.S.		into 1971
9. Effect of Temperature on Movement of Oil on the Shore. Observations have been made of the surface temperature and the associated movement of oil on rocky shorelines in Chedabucto Bay.	Atlantic Oceanographic Laboratory, Dartmouth, N.S.	J.N. Pew	August 1970
10. Long Term Study of the Properties of Shore-Bound Oil.	Fuels Research Centre Mines Branch, Ottawa, Ont., and Chemical Eng. Dept., N.S. Technical College, Halifax, N.S.	D.S. Montgomery A.Y. McLean	September 1971
11. Spreading Chearacteristics of Bunker C	Chemical Eng. Dept., N.S. Technical College, Halifax, N.S.	A.Y. McLean	September 1970
12. Properties of Sea Water-in-Bunker C Emulsion	Chemical Eng. Dept., N.S. Technical College, Halifax, N.S.	G.D.M. MacKay	September 1970

Project	Agency	Scientist in Charge	Completion Date
13. Residual Effects of Oil Contamination on the Algal Flora of Chedabucto Bay, N.S.	Atlantic Regional Laboratory, National Research Council, Halifax, N.S.	J.S. Graigie, T. Edelstein. and J.L. McLachlan	
14. Application of Combined Chromatographic - Spectrometric Techniques to Identify Sources of Oil Contamination	Atlantic Regional Laboratory, National Research Council, Halifax, N.S.	O.Hutzinger and W.D. Jamieson	
15. Biodegradation Study in Chedabucto Bay, N.S. Water, beach and bottom samples from Chedabucto Bay are being collected for biodegradation studies under controlled laboratory conditions simulating conditions in Chedabucto Bay.	Fisheries Research Board of Canada, Halifax Laboratory, Halifax, N.S.	J.E. Stewart	Continuing into 1970
16. Intertidal and Benthic Studies Monthly sampling of intertidal and benthic fauna is acontinuing at collected sites in Chedabucto Bay, to study the persistence of oil in the biota and any sublethal effects upon the biota.	Marine Ecology Laboratory, Dartmouth, N.S. and Fisheries Research Board, St. Andrews	M.C.H. Thomas D.J. Scarratt	Continuing